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Some notes on the fuel consumption of main line railways,

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Accurate and complete information on the construction of steam locomotives and their working under constant load are given in many good technical works on these engines.

It is less usual, however, to find particulars of general investigations intended to ascertain the efficiency of steam traction, first under varying load conditions, and then in ordinary working, taking into account the many requirements involved in steam traction, for starting, washing out, standing in reserve under steam, getting the engine ready and putting it away in the depot. The results of such investigations are not as a rule allowed to leave the files of the railway for many reasons, the most important being the essentially empirical character of the methods used and because they apply particularly to the railway in question.

In the present article we propose :

1. to note briefly the general results already given by different authors, as regards the working of locomotives under constant load, showing them in the form of a system of constant efficiency curves, drawn in terms of the speed and the indicated tractive effort (or at the wheel tread);

2. to show how, starting from these constant efficiency curves and the records taken by the speed recorders, the average efficiency or the consumption of a locomotive, when running, can be readily calculated.

The effective efficiency or the consumption in « road service » can be deduced from the values of the efficiency or from the quantity consumed when running, by adding to the latter the amount used for lighting up, light running, auxiliary working, etc., accessory consumptions the approximate values of which are obtained from direct experience and from systematic records collected in the depots;

3. to investigate how the average fuel consumption has varied during the last fifty years on various railways, by endeavouring to bring out the relations which exist between the consumptions, the average characteristics of the corresponding locomotives in the stock, and the general conditions of user of the engines.

We hope that reading the present note will lead the engineers actually in charge

of the organisation of the traction services to complete the methodical information collected by the premiums and mileage services so as to obtain from them something more than an equitable allocation of the premiums between the enginemen.

Very important steps moreover have been taken on various railways so as to enable the management of the companies to exercise an enlightened and vigilant control over the operating conditions of the various lines of the system, and to reduce the capital locked up, as well as the expenditure on staff and material.

I. — Working of steam locomotives under constant load.

The working of steam locomotives under given running conditions, constant speed and admission for example, can be investigated in two different ways, either by tests at a fixed point in special testing plants fitted with hydraulic or electric brakes, or by trial out on the line by means of a dynamometer car and a brake locomotive (Lomonosoff-Czeczott method).

The United States were the first to build fixed testing plants, the Lafayette testing plant of the University of Purdue being built about thirty years ago : Professor Goss carried out, from 1905 onwards, in this testing plant, the first investigations into the allocation of the losses as between the fireboxes, boilers, motor and mechanism.

Other testing plants were built before the War, the principal being those at Champagne, for the University of Illinois, and at Altoona for the Pennsylvania Railroad.

Since the War, two testing plants have been built : one at Swindon in England, the other at Berlin-Grünewald in Germany. The French railways are building, at Vitry, a similar plant which will be put into use in a few months time.

The data obtained in the American testing plants have for some time been the principal source of exact information on steam locomotives, although the results obtained with a fixed plant are always more favourable than those obtained in running tests, from the fact more especially of the suppression, or to be more exact, the reduction of the losses by radiation and convection, which increase with the running speed and which are far from being negligible.

The Lomonosoff-Czeczott method, which has been put into use relatively recently, consists of running over the line a *driving* locomotive with constant admission and pressure, and a second *brake* locomotive, constantly regulating the resistance, so as to maintain constant speed. A dynamometer car put between the two locomotives is used to measure at each instant the pull and power at the drawbar, at the same time that a certain number of characteristic particulars in connection with the running, temperature, pressure, etc., are recorded.

As a matter of interest, we would like to remind our readers that we were responsible for the proposal to replace the steam brake dynamometer by an electric locomotive with rheostatic braking, as already largely used on the French Midi Railway, with the addition of certain supplementary recording instruments in order to make the dynamometer car unnecessary.

Efficiencies at constant load.

The pamphlets published by the Pennsylvania Railroad from 1915 to 1919, dealing in most cases with tests on locomotives of the *Pacific*, *Mikado* and *Decapod* types, contain fairly full and ac-

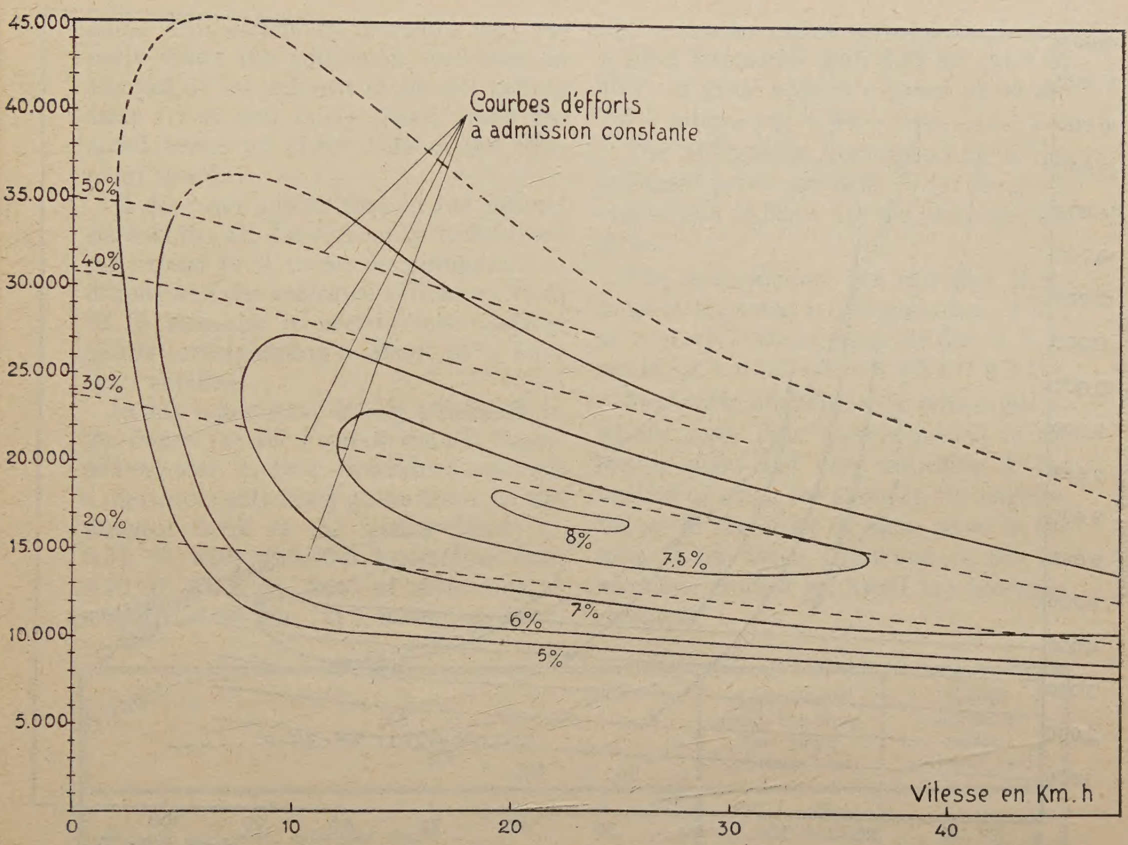


Fig. 1. — Constant efficiency curves in terms of the effort at the wheel tread and of the speed $\eta = f\ (F, v)$ (approximate). — I 1 S *Decapod* Pennsylvania Railroad locomotive.

Explanation of French terms:

Courbes d'efforts... = Effort curves with constant cut-off. — Vitesse en km./h. = Speed in kilometres per hour.

curate data, by means of which it is possible to draw the curves of efficiency at constant admission and at variable speed. From this first curve it is possible to deduce, as we have done, the curves of constant efficiency in terms of the effort at the tread of the wheel and of the speed, $\eta = f\ (F, v)$.

Figure 1 gives the result of this calculation for a 2 900-H.P. *Decapod* locomotive of the Pennsylvania Railroad.

With this diagram it is possible to follow easily the working of the engine under the different working conditions possible.

The Pennsylvania Railroad engine being already rather old (13 years), we also give the constant efficiency curves for locomotives of recent construction: a *Mikado* engine of the Moroccan Railways put into service in 1932; this last engine is a compound and is fitted with the Kylchap exhaust and the Dabeg feed water heater.

The examination of these curves shows that the efficiency of the steam locomotives varies very widely and that it only

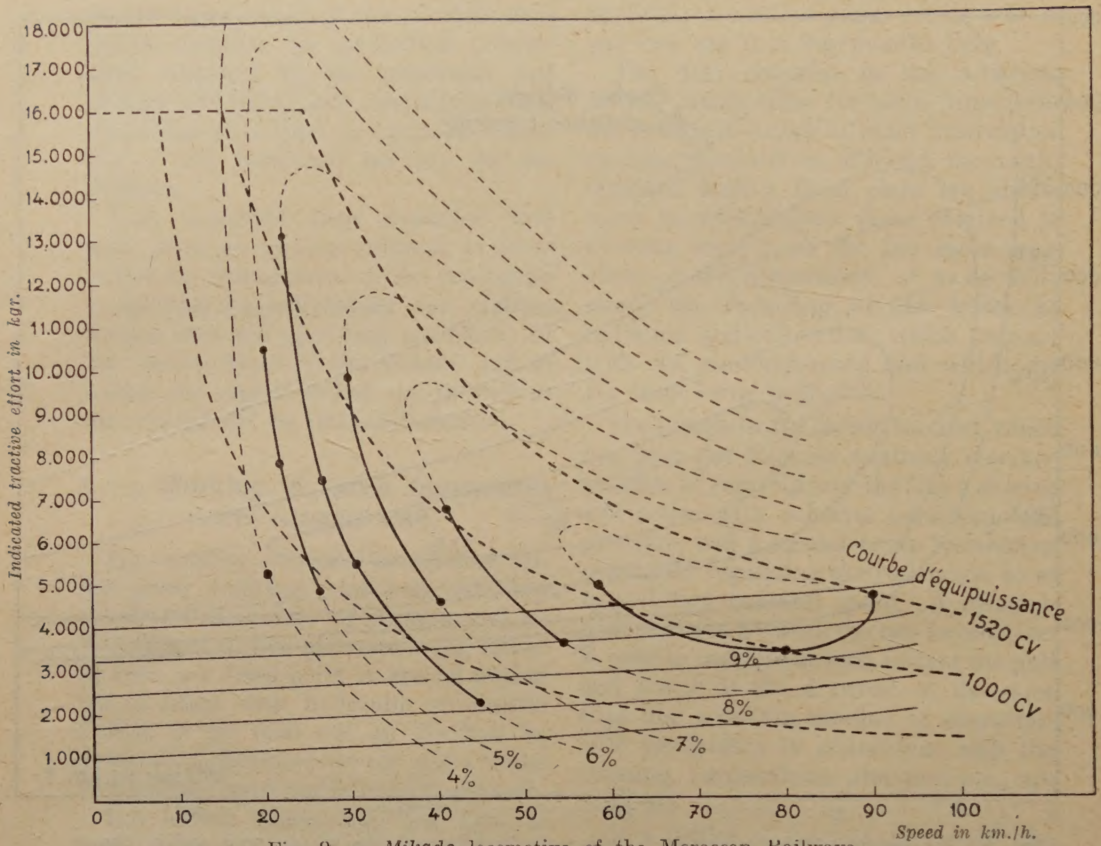


Fig. 2. — *Mikado* locomotive of the Moroccan Railways.
Constant efficiency curves for the indicated power.
Professor Czeczott's tests : Chrzamous Works :

Pressure 14 kgr./cm² (199 lb. per sq. inch).
Grate area 3.8 m² (40.7 sq. feet).
Kylchap exhaust.
Dabeg feed water heater.
2 cylinders : diameter, 620 mm. (24 13/32 inches).

Piston : stroke, 700 mm. (27 35/64 inches).
Diameter of driving wheels, 1 650 mm. (5 ft. 5 in.).
Adhesive weight, 72.5 metric (71.3 Engl.) tons.
Cylinder volume swept out by the piston : 208 litres (7.342 feet).

exceeds 7 % (in the case of the indicated power) for very limited speed and tractive effort conditions.

In figure 2 we have drawn a group of curves representing the indicated tractive effort corresponding to operating the locomotive alone on the level and on a gradient of 5 %, 10 % and 15 %, in order to fix the practical limits of working in useful service.

The consideration of these curves shows on the one hand why the fuel consumption of locomotives running light is so variable, and also why the quantity of coal burnt by the engine to move itself is so great, and is in general according to the load between 30 % and 50 % of the total consumption.

These curves show that the maximum efficiency is obtained with an admission of between 15 and 25 % and with speeds of the order of 3 to 4 revolutions per sec-

ond. This efficiency decreases very rapidly when the admission increases on account of the exhaust steam not getting away freely and fairly slowly when the speed varies on either side of the optimum speed.

It does not appear that in the present state of the art the efficiency at the tread can exceed 10 % under the optimum conditions and the indicated efficiency 11 to 12 % although in certain tests isolated points corresponding to about 13 % have been obtained.

In his noteworthy article published in the *Organ für die Fortschritte des Eisenbahnwesens*, in 1931, Nordmann reported a maximum efficiency at the tread (at the drawbar hook in the testing plant) of 9.97 % with a 2-10-0 locomotive with 4.70 m² (50.6 sq. feet) of grate area at a speed of 35 km. (21.7 miles) an hour, and a similar efficiency of 9.96 % with a 2-6-2 locomotive with 2.04 m² (21.9 sq. feet) of grate area at a speed of 60 km. (37.3 miles) per hour.

The efficiencies corresponding to the indicated power are 10.55 % for the goods engine and 11.82 % for the passenger engine.

The consumption per effective H. P.-hour at the tread is 905 grammes (2 lb.) of coal of 7 000 calories (12 600 B. T. U. per lb.) i. e. 6 335 calories (25 137 B.T.U.).

The maximum efficiency values obtained are lower than those recorded in the testing plant and vary according to the method of using the steam in the engines. Values of the order of those given in the table below taken from one of the remarkable studies by Nadal are generally accepted.

TYPE OF LOCOMOTIVE.		Approximate steam consumption under optimum load. Kgr,	(*lb.*)	Overall efficiency under optimum load.
Simple expansion, saturated steam		11.0	(*24.25*)	5.1 %
Compound, saturated steam		9.5	(*20.95*)	5.9 %
Simple expansion, superheated steam, 300 to 320° C. (572 to 608° F.)		9.0	(*19.84*)	5.8 %
Compound, superheated steam, 300 to 320° C. (572 to 608° F.)		8.0	(*17.64*)	6.5 %
Compound	superheated steam, 360 to 380° C. (680 to 716° F.); feed water heated to 95° C. (203 F.)	6.0 to 6.5	(*13.23* to *14.33*)	9 to 8.2 %

General allocation of losses as between the different parts of the locomotive.

The overall efficiency of a steam locomotive depends upon the efficiencies of the three machines which form it : boiler and firebox — steam engine — transmis-

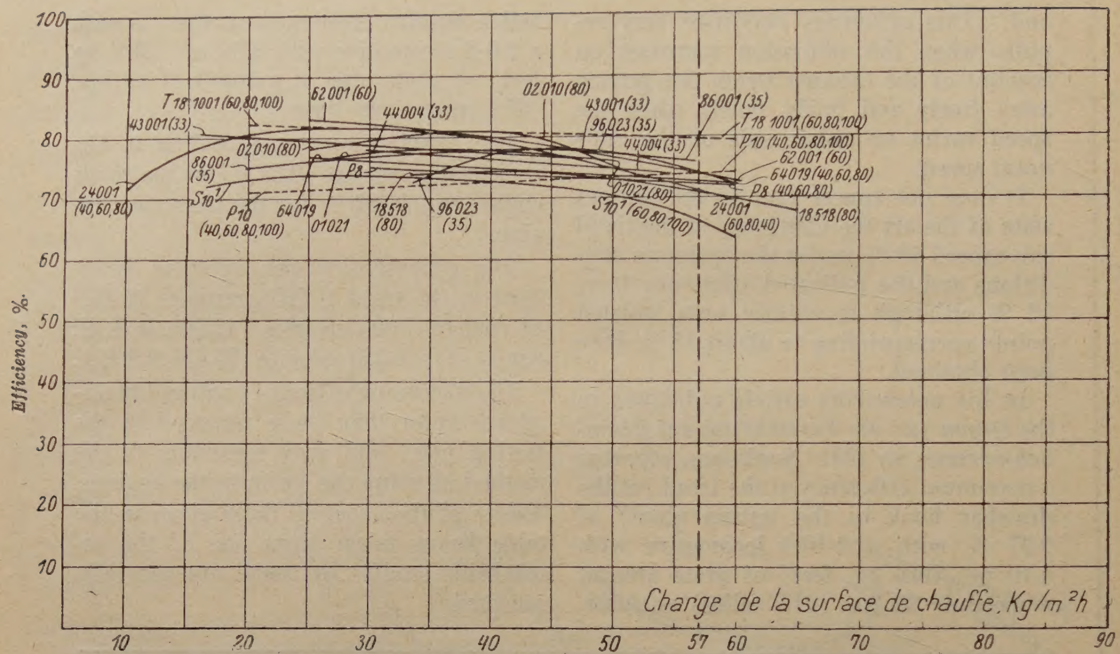


Fig. 3. — Efficiency of the boilers during road tests in terms of the weight of fuel per square metre of heating surface.

Note: Charge, etc... = Load of heating surface, kgr. per sq. metre of grate area per hour.

sion mechanism, the individual efficiencies themselves being functions :

— for the boiler : of the rate of combustion;

— for the engine and mechanism : of the point of admission and of the speed.

The efficiency of the locomotive boiler is very high owing to its design, although the rate of combustion is nearly 10 times greater than that formerly considered economical in stationary boilers.

The efficiency of the boiler which reaches 85 % under optimum load, falls very rapidly with the rate of coal combustion and is about 50 % for rates of 600 to 800 kgr. per m² (122.8 to 163.8 lb. per sq. foot) per hour, sometimes reached in the United States. The discussions on the conditions of application of the Strahl formula on the coefficient of evaporation of the boilers show that it is at the present time impossible to give a formula defining this coefficient q (quantity of steam produced per kilogramme of coal burnt) in terms of the rate of combustion $\frac{Q}{G}$ quotient of the hourly production of steam by the grate area. Figure 3 taken from the above mentioned article by Nordmann shows that the efficiency of the boilers is very variable from one engine to another and that measured at the testing plant under the optimum load it is between 72 and 83 % (rates of combustion of between 20 and 40 kgr. of water per m² [8.1 lb. per sq. foot] per hour).

An average value of 75 % under optimum load should not be exceeded under

normal operating conditions on the railways.

Efficiency of the motor and of the mechanism.

The efficiency of the locomotive steam engine can be divided into the two elements, the first corresponding to the motor properly speaking, and to the indicated power, the second to the driving mechanism and to the power at the tread. In the fixed testing plants these two efficiencies are measured directly, whereas in other methods of test carried out on the line with a dynamometer car and a brake locomotive only, the indicated efficiency and the efficiency at the drawbar are measured directly.

The heat efficiency of the engine depends very largely upon the design of the engine and the valve gear. Just as the replacement of flat valves by piston valves was a notable improvement, the use of poppet valves of the Caprotti, Chapelon or other types, will also show further savings; all the improvements made since the War to reciprocating steam engines, fixed or semi-fixed Lenz or others, ought in turn to be applied to steam locomotives. We know the difficulties encountered when getting out the theory of the reciprocating steam engine, especially when it has free exhaust, just as we know the gaps still existing in this theory on which the work of Strahl in spite of certain disputable hypotheses is one of the most complete.

The curves given in the article mentioned above by Nordmann, while bringing out the very great differences between locomotives, show that the overall heat efficiency of the engine (relatively to the indicated horse power) is about 13.2 % : consumption of steam at 15 kgr. (213 lb. per sq. inch) pressure at 4 755 calories (18 868 B. T. U.) per indicated H. P.-hour.

The theoretical efficiency of the engine (Rankine cycle) deduced from the Mollier diagrams to which we will return later, being 16.7 %, we see that, as regards the steam engine, the reciprocating engine of this locomotive has an efficiency of 79 % :

$$13.2 = 16.7 \times 0.79.$$

Most of the other modern engines tested at Grünewald have « specific efficiencies » lying between 79 and 67 %; these specific efficiencies are excellent in view of the small power of the locomotives : it is possible to form a better idea of their high value by comparing them to the specific efficiencies obtained with steam turbines of different power.

Figure 4 gives the values of the specific efficiencies of modern steam turbines with one or two exhaust flows and condenser vacuum lying between 93 and 95 %, used in getting out schemes.

Examination of this figure shows that the modern steam locomotive of 1 500 to 2 500 H. P. has a specific efficiency of the same order as turbines with free exhaust of similar power, and condensing turbines of appreciably higher power.

It may be pointed out that investigations carried out on turbines show that now that experience has made it possible to determine the most suitable dimensions, every endeavour to increase the theoretical efficiency generally results in a reduction to the same extent of the specific efficiency.

Thus an increase of « expansion » makes the construction difficult owing t the large volume occupied by the low pressure steam, and an increase in « temperature » involves other difficulties such as that of a satisfactory utilisation of the

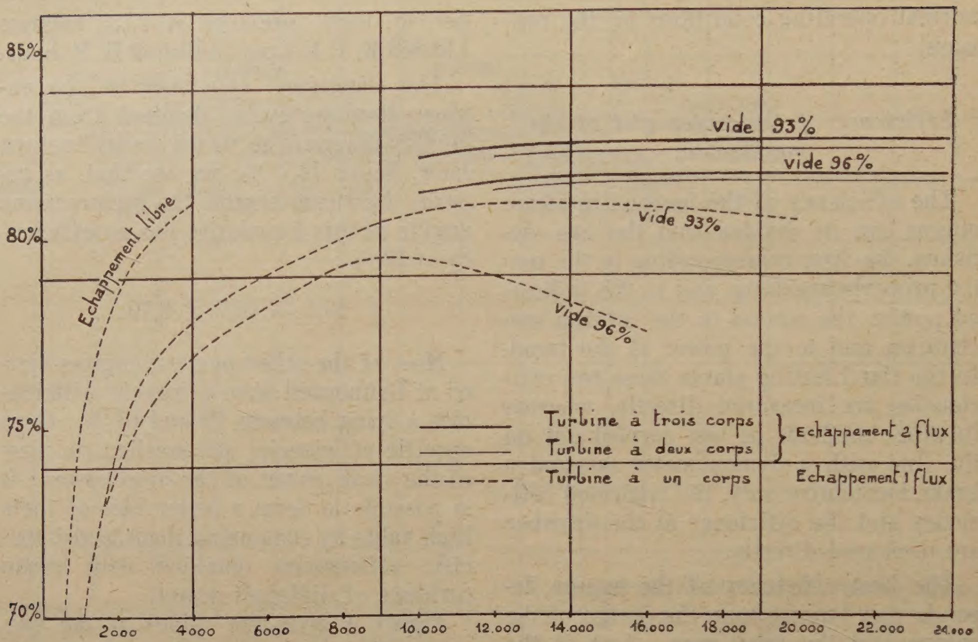


Fig. 4. — Diagram of the specific efficiency of steam turbines in terms of the power.

Explanation of French terms:

Echappement libre = Free exhaust. — Vide = Degree of vacuum.

——— Turbine in three groups, ——— Turbine in two groups: Two exhaust flows.
- - - - - Turbine in one group: One exhaust flow.

heat available at all speeds and under all loads.

As regards the efficiency of the mechanism the ratio between the power at the tread to the indicated power is between 75 and 90 %, the lower value corresponding to the highest speeds.

Overall efficiency at the tread.

The overall efficiency at the tread resulting from the combination of these three successive efficiencies : boiler, motor, mechanism, should not therefore exceed :

$$0.82 \times 0.79 \times 0.90 = 0.60,$$

taking the maximum efficiencies of the boiler, of the engine and driving gear as being found under the same load, which is not generally the case.

The maximum maximorum efficiency corresponding to a pressure of 14 kgr. (199 lb. per sq. inch) and a superheat of 320° (608° F.) can therefore not exceed, seeing that the theoretical efficiency is 16.7 % :

$$0.167 \times 0.60 = 0.167 \times 0.82 \times 0.79 \times 0.90 = 0.10.$$

Actually the maximum efficiency at the tread recorded in tests in the Grünewald testing plant does not exceed 9.97 %.

In the many tests carried out on the line, it has been found possible to approach this value of the efficiency, without however ever reaching it, no actual

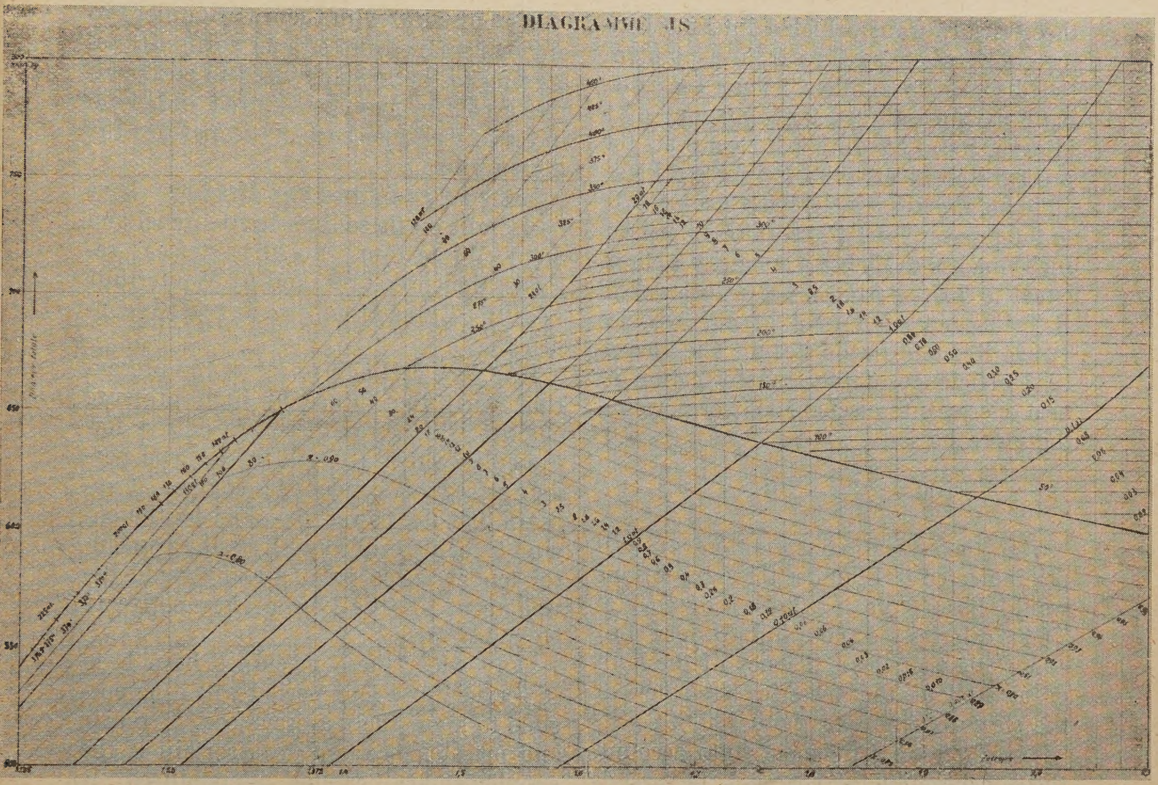


Fig. 5. — Mollier's diagram.

line having a sufficiently regular profile for it to be possible by a careful selection of the load and speed to work constantly under the conditions of maximum efficiency.

Recently tests of this kind were carried out with the *Pacific* type engine of the Paris-Orleans Railway and the *Mountain* type locomotives of the Est and the Paris-Lyons-Mediterranean Railways : the very interesting results obtained have only confirmed what we said above, on the one hand on the subject of the value of the maximum efficiency, and on the other on the narrow range of speed and efforts corresponding to this maximum efficiency.

Endeavours made to increase the maximum practical efficiency by increasing the theoretical efficiency. — Use of very high pressures and of condensing.

The progress made at the present time in electric power stations, both as regards the use of high pressures and as regards condensing, have encouraged the railway companies to use similar arrangements on locomotives, in spite of the difficulties resulting from the limitations of gauge and weight. The consideration of the Mollier diagrams reproduced in figure 5 makes it possible to show immediately the value of the energy usable or

theoretically transformable into mechanical work when passing from a point of the diagram to another. Thus the adiabatic expansion (constant entropy) of a kilogramme (2.2 lb.) of steam at the pressure of 14 at. (199 lb. per sq. inch) and the superheated temperature of 320° to the pressure of 1.1 kgr. (15.6 lb. per sq. inch) makes available a quantity of heat equal to 737 — 614 = 132 calories (528 B. T. U.) out of a total of 737 calories (2 924 B. T. U.) in the steam. The theoretical efficiency of the transformation of heat energy into mechanical energy would therefore be

$$100 \times \frac{123}{737} = 16.7\ \%.$$

The theoretical consumption of coal per indicated H. P. under these conditions would be 540 gr. (1.19 lb.) of coal at 7 000 calories (12 600 B. T. U. per lb.) supposing that the efficiency of the boiler as well as the specific efficiency of the steam engine were both 100 %.

Taking these efficiencies into account, the consumption of coal will be practically doubled as we have already seen.

The use of very high pressures or of condensing obviously makes it possible to obtain theoretical efficiencies very much higher and the examination of the diagram shows that theoretical efficiencies are reached of :

25 % starting from a pressure of 60 at. (853 lb.) and a temperature of 400° C. (752° F.) to a pressure of 1.1 kgr. (15.6 lb.) (free exhaust) : $\frac{762 - 570}{762} = 0.25$;

28 % starting from a pressure of 14 at. and a temperature of 320° (608° F.) to a pressure of 0.10 kgr. (1.42 lb.) (condensation) :

$$\frac{737 - 570}{737} = 0.28.$$

We only deal with the question here in an elementary and simple form as, according to the methods used to carry out the cycle, it may be desired either to increase the superheat or to increase the pressure drop.

Extremely interesting engines have been built on these lines by Henschel and Sohn, Winterthur (Buchli), etc... as regards high pressures, and by Winterthur (Zoelly), Ljungström, etc., as regards condensing.

It is very difficult to say at the present time what the future of high pressure engines will be, as there are only a few examples which are still in the trial period; as regards condensing engines, it appears that the power absorbed by the engine to haul itself as well as the condenser tender is too great for any rapid development of this type of locomotive to be hoped for.

Only when these machines have been in service for a long period will it be possible to know their average cost of repair and maintenance, and to ascertain if the supplementary capital immobilised is compensated for by the operating savings realised.

As regards the danger inherent to the use of very high pressures, this appears to be much less than that run twenty years ago with pressures of 16 kgr. (227 lb. per sq. inch) in view of the experience now obtained in the use of special metals for high temperatures.

In spite of the theoretical possibilities of improving the efficiency by the use of high pressures and condensing, it is probable that the evolution of the steam locomotive will continue rather in the progressive increase of the pressure and of the superheat, the use of pressures of about 20 kgr. (284 lb. per sq. inch) now appearing to give valuable advantages from the point of view of the power ob-

tainable. Thus the 241 type locomotives of the Paris-Lyon-Mediterranean Railway give, at the same time as a high efficiency, an indicated H. P. of 3 000 for a grate area or 5 m² (53.8 sq. feet).

II. — Fuel consumption under varying load.

The consumption under varying load is that recorded daily when dealing with the running of any particular train on the line and the supplementary consumption inherent to steam traction (lighting up, standing pilot, etc.), can be readily deducted; these supplementary consumptions do not exist either in the case of automobile traction or in electric traction.

In fact when a steam locomotive is in running order and ready to take service, it contains in the form of incandescent fuel and water already heated a considerable quantity of energy. In a steam engine burning oil or pulverised coal the accumulation of energy is much lower, because it limits itself to the heating of the water of the boiler and the walls of the firebox. The efficiencies that we have spoken of previously do not take this accumulation of heat into account, because we have only dealt with constant running conditions under constant load.

When running under varying load, the accumulation of the heat energy of the water and the firebox plays a very important part; the driver and fireman cannot with ordinary firing regulate as desired and instantaneously the rate of combustion. The quantity of hot water containing the reserve of heat units available in case of need corresponds nearly to a height of water of about 10 cm. (3 15/16 inches) over an area equal to that of the surface of the water. It is a question therefore of 1 000 to 1 500 litres (220 to 330 Br. gallons) of hot water representing 150 to 200 H. P.-hours.

Consumption when running.

The calculation of the consumption of fuel when running can be carried out approximately when we know :

1. The characteristics of running of the engine under the form of curves of constant efficiency, such as those dealt with previously;

2. The speed-distance running diagram, such as is given by the locomotive speed recorders (Flaman, Hausshaelter, Teloc, etc.). At the present time, on the French railways at least, these diagrams are only used for checking the safety as regards the running speed or as regards the observation of signals. These diagrams which can easily be completed by showing on them the periods of running with regulator closed, should in the future be used by the premiums and mileage services for checking the coal consumption.

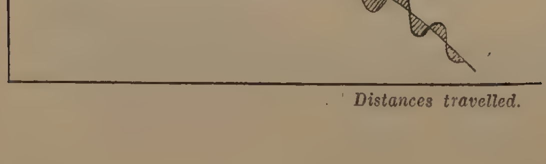
These recorder diagrams which represent the relation $v = f(s)$, when taken in connection with the profile of the corresponding line, make it possible to ascertain the variation of the indicated tractive effort as a function of the distance and the speed. This calculation can be made by using the usual empirical formulæ giving as a function of the speed the values of the running resistance of the locomotive and the stock hauled. — We will return later on to the method of using these formulæ as regards the locomotives. — As regards the local efforts due to the curves and to the gradients, they are obtained from the profile of the line. — As regards inertia forces (acceleration or retardation forces) they can be calculated from the speed recorder diagrams.

This series of calculations enables us to find at each point of the journey the speed and the total indicated tractive effort (or at the tread according to the formulæ used).

From this curve of total tractive effort — speed (or distance) we can easily deduce the consumption of steam which depends directly upon the energy produced each time each cylinder is swept through. All that is necessary is to use a set of curves similar to the set of constant efficiency curves giving for each point of speed — effort the consumption of steam. We can then pass from the consumption of steam to the consumption of fuel by using a set of evaporation curves. It appears much simpler and easier to calculate directly the consumption of fuel by using our set of constant efficiency curves, taking into account the regularity of the rate of combustion resulting from the existence of the « heat accumulators » about which we have spoken above.

The existence of this reserve of energy makes it possible to change the rate of combustion in a slow and progressive way only, the increase of draught resulting from an increase of load automatically regulating the average combustion.

The curve of calculated efforts being the saw tooth curve similar to that represented by the figure given here, a free curve can be drawn through it, provided the exchanges of energy above and below (hatched areas) balance as a whole and do not exceed individually the value of 150 to 200 H. P.-hours, according to the type of locomotive.



The parts cross hatched which represent energy should therefore each have an area inferior to the corresponding surface at the scales selected for 150 to 200 H. P.-hours.

This question of regulation might be treated more exactly by using similar methods to those employed in calculating buffer accumulator batteries, but in the present case great mathematical precision appears to be useless; it must not be forgotten in fact that the fireman and driver themselves on each journey carry out this adjustment; the differences of consumption that we record between engines of the same type on the same service but driven by different sets of men result in part from the method of regulation adopted in practice by the set of men.

If we refer to the curves of constant efficiency for the indicated tractive power (or at the tread according to the case), it is possible to dimension the curve of the adjusted efforts as efficiencies, because for each point of the journey we know the effort at the tread and the speed.

This operation once done, it will be easy to draw the curve $\frac{F}{\eta}$ and to make the integration $\int \frac{F}{\eta} \, ds$.

The area so found is proportional to the consumption of fuel when running.

In order that this calculation may be carried out correctly it is necessary that the speed recorder diagrams should show

the periods of running with the regulator closed.

If considered more convenient, other variables can be taken, for example the indicated power in place of the indicated effort, but fundamentally the method remains the same.

* * *

Observations on the formulæ for locomotive running resistances.

We know that the tractive efforts on level and straight line corresponding to a given rolling stock and service, can now be calculated by empirical formulæ representing the facts within an error of ± 5 %, when properly employed.

As regards locomotives the question is more complex, as the resistance at the tread observed when running, the locomotive hauling a train, is not in any way the same as that measured when running with closed regulator or when coasting for example.

It now appears probable that thanks to the multiplication of testing plants and the more highly developed methods of carrying out running tests on the line, this question of locomotive running resistance and of the losses in the driving mechanism will be completely elucidated. Although the idea of the tractive effort at the tread is a fundamental mechanical idea, it appears that in the future the running resistance of the machines should be considered as a loss measured, at the same time as the losses in the mechanism, by difference between the indicated tractive effort and the pull at the drawbar hook, the engine running on straight level line, the indicated efforts and the efforts at the drawbar hook alone being arrived at experimentally.

Consumption when standing and during certain usual shunting operations.

The consumption when running at the head of a train only forms a part, though obviously the most important, of the total consumption, as the locomotive continues to burn coal even when producing no useful work.

In order to arrive at the total consumption in ordinary service it is necessary to ascertain a series of « unit consumptions » corresponding to the most usual working conditions, engine by itself, such as : lighting up, standing under pressure in the depot, standing in reserve in the depot or in a station, etc.

These coefficients can be calculated with a fairly close approximation, but it is better to ascertain them by direct test, in the depots, either with ordinary engines, or with oil-fired engines which lend themselves better to the measurement of the fuel consumed in the auxiliary services.

As the steam locomotives can be considered first of all approximately as engines geometrically alike, all the characteristic ratios of the dimensions of the boilers being more or less the same for all the engines, it is natural to relate all these coefficients to one square metre of grate area.

The values of the principal unit coefficients that have to be taken into consideration normally are given below :

Lighting up the engine and heating the water to 70°.

Coal, 60 to 75 kgr. per m² (12.3 to 15.4 lb. per sq. foot) of grate area. For a grate area of 2.60 m² (28 sq. feet) (average grate area of the present stock of steam locomotives of the French railways), the corresponding consumption will be comprised between 150 and

200 kgr. according to the volume of water contained in the boiler.

Preparation of the locomotive (air pump not working).

18 kgr. per hour and per m² (3.68 lb. per hour and per sq. foot) of grate area — [on the average 47 kgr. for G = 2.60 (103.6 lb. for 28.0 sq. feet of grate area)].

Compensation for the radiation and convection losses with the air pump working.

36 kgr. per hour and per m² (7.36 lb. per hour and per sq. foot) of grate area — [on the average 94 kgr. for G = 2.60 (207.2 lb. for 28.0 sq. feet of grate area)].

Standing under pressure between two runs.

8 to 10 kgr. per hour and per m² (1.63 to 2.05 lb. per hour and per sq. foot) of grate area — [on the average 21 to 26 kgr. for G = 2.60 (46.3 to 57.3 lb. for 28.0 sq. feet of grate area)].

Light running from the depot to the station and vice-versa including setting back onto the train.

Value varying round 45 kgr. per hour and per m² (9.2 lb. per hour and per sq. foot) of grate area — [on the average 120 kgr. for G = 2.60 (264.5 lb. for 28.0 sq. feet of grate area)].

Shunting service.

45 to 50 kgr per hour per m² (9.2 to 10.2 lb. per hour and per sq. foot) of grate area.

III. — Locomotive coal consumption in road service.

The life of a steam locomotive during each period in steam being defined on all the railways by an individual time table which constitutes the engine working, it is possible to calculate the total consumption corresponding to each turn of the link, by adding up the consumption when *running* and the *accessory* consumptions.

This total consumption is what is known as the consumption in road service.

From the practical point of view, this consumption is the one which has to be brought down, and we know that in order to get as satisfactory working as possible the railways have interested their staff in the efficiency by awarding them premiums, some based on the mileage, others on the savings of fuel and lubricating materials.

As a general rule, the premiums distributed to the staff are calculated in terms of the savings effected in *running* by the enginemen and at the *depot* (auxiliary services) by the non travelling staff.

These savings are calculated by comparing the actual consumption with the allowances.

Fuel allowances.

The fuel allowances for running are actually fixed in the depots almost entirely empirically, each class of men sharing the premium resulting from the application of the regulations.

No technical consideration enters into the preparation of the allocations, and no physical consequence can be drawn by comparing them with the actual consumption.

The indications previously given show that it is possible, however, to calculate the consumption of fuel when running, either for an engine the curves of constant efficiency of which are known, or for a hypothetical machine working at constant efficiency.

If the allocations were fixed by taking as basis the result of these calculations, it is clear that the comparison of the real consumptions with the allocations make it possible to determine the mean value of the efficiency when running of

a given series of engines for the working considered.

By means of calculations made once for all, the organisation of the premiums and mileage service makes it possible to calculate regularly, monthly for example, the average efficiency on the road and the average effective efficiency (accessory losses included) of the engines of each type in each link. It would then become possible to compare in an equitable manner the driving and maintenance conditions of a given class of engines in different depots or different types in a given depot or in certain depots.

As far as I know, no railway is organised in such a way as to be able to determine systematically the real efficiency of its engines and all that can be deduced approximately from the present statistics is the overall average efficiency of a system, as we will show later on. The figures given in the technical publications all relate to individual tests carried out under exceptional conditions, whether from the point of view of the condition of the engine tested, or that of the staff used to drive it.

The examination of the monthly statistics of the depots shows that for a given link and a given type of engine, the consumption of the different sets of men varies between two limits corresponding one to the average consumption increased by about 10 % and the other to the same average consumption reduced by about 10 %. In other words, for a given service the variation between the average consumption and the minimum consumption is about 10 %.

If we reflect a little upon the matter, we appreciate that the consumption of the different engines in the same link when they are considered as a whole should be distributed according to the laws of probabilities, and the corresponding [1] probable variation, defined by Gauss' law, should have a value of about 2 %.

The precision obtained therefore in practice is much greater than it appears to be at first sight, the causes of the variation being extremely numerous and varied; the loading of coal on to the tenders is still counted in « baskets » in many depots, a process which obviously is in no way accurate.

It is only in the important depots that the coal is really weighed.

It would therefore be wide off the mark to say that the practical average running consumption is equal to the consumption in the tests which were carried out with all possible precautions to get the lowest consumption. The variation between the test consumptions and the practical average consumption is generally about 10 % from the fact of the unavoidable « dispersion » of the consumption.

Mean overall efficiency of steam traction for a railway as a whole.

We have said that owing to the lack of methodically prepared statistics, it is at the present time impossible to determine the average efficiency of steam traction, link by link, or depot by depot, without making lengthy calculations, all depending upon more or less plausible hypotheses.

It is possible to calculate however fairly easily the average efficiency of steam traction for the whole of a railway when

(1) As is known, Gauss' law fixes for the probable variation a value equal to 1/8th of the dispersion when, for a great number of trials about 2 % having the greatest variations are eliminated, and 1/10th when only 1 % are eliminated of the tests with the widest differences.

the consumption of coal and the complete traffic statistics are known for each class of engine. This calculation is made by working out separately the total work developed at the drawbar in passenger service and in goods service, and comparing this « useful work » to the coal consumption corresponding to each service.

In the very frequent case in which these consumptions are not known separately, their total is known and instead of calculating the actual efficiency of each service (fast and slow traffic) we have to be satisfied with the calculation of the average efficiency.

This method of calculation is found to have many weaknesses when it is desired to transfer the results from one railway to another, as it is very obvious that the average running resistance of the rolling stock hauled which depends upon the speed and the type of loading is not the same on all the railways; the work per tonne-kilometre hauled is evidently much smaller on the French Est Railway in the case of wagons loaded with iron ore than on the Paris-Orleans for wagons loaded with agricultural products [1].

[1] The formula that should be used for a systematic calculation of the resistances in terms of the load of wagons is in the form

$$r = \left(a + \frac{b}{P}\right)(\alpha + \beta V^2)$$

as we have shown in previous studies.

In this formula, in agreement with the tests carried out by the Pennsylvania Railroad and other railway companies :

P represents the average weight of the wagon carrying the average load, V represents the speed.

We often take in our calculations the formula :

$$r = \left[0.6 + \frac{25}{P}\right]\left[1 + \frac{V^2}{4\ 000}\right]$$

However this may be, some progress will be realised in the knowledge of this phenomenon by allowing a different amount of useful work per tonne-kilometre hauled in passenger service to that allowed per tonne-kilometre hauled in goods service. The average value of useful work at the drawbar per gross tonne-kilometre hauled will vary therefore in terms of the relative proportions of the passenger and goods traffic.

We shall get still closer to the truth by grouping the trains into three classes instead of two — Express and fast passenger — Ordinary passenger — Goods — and by attributing to each category a given value of useful work per gross tonne-kilometre hauled.

We finally get a very high degree of exactitude by calculating, as we have proposed above, the value of the work per gross tonne-kilometre hauled for each engine working.

Until the traction services are organised in such a way as to supply accurate factors for the calculations we have laid down, we must limit ourselves to indicating briefly the results of the approximate calculations made by classifying the trains into two groups only : Slow and Fast.

In order to decide the values of the useful work corresponding to each kind of service, we have calculated line by line the consumption of energy, for a given railway, in fast and slow service, taking for each kind of service the running resistance at the average running speed of the trains.

Calculating the average values of these resistances, giving to each of them a weight proportional to the traffic, we have obtained the following results :

Useful work corresponding to hauling one tonne-kilometre

(one Engl. ton-mile).

Distribution of the average work.	Rolling stock hauled.				Tractive stock.			
	Carriages, passenger service.		Wagons, goods service.		Locomotives : Fast traffic.		Locomotives : Slow traffic.	
	Kg.-M. per tonne-km.	*Ft.-lb. per Engl.-ton-mile.*	Kg.-M. per tonne-km.	*Ft.-lb. per Engl. ton-mile.*	Kg.-M. per tonne-km.	*Ft.-lb. per Engl. ton-mile.*	Kg.-M. per tonne-km.	*Ft.-lb. per Engl. ton-mile.*
Running resistance	3 350	*(39 618)*	2 400	*(28 380)*	9 260	*(109 500)*	8 160	*(96 492)*
Curves	305	*(3 607)*	310	*(3 666)*	305	*(3 607)*	310	*(3 666)*
Starting and braking . . .	520	*(6 149)*	272	*(3 216)*	520	*(6 149)*	272	*(3 216)*
Gradients	982	*(11 612)*	1 175	*(13 894)*	982	*(11 612)*	1 175	*(13 894)*
	5 157	*(60 986)*	4 157	*(49 156)*	11 057	*(130 868)*	9 917	*(117 268)*

That is in round figures for the stock hauled :

5 200 Kg.-M. (61 490 foot-pounds) in passenger service,

4 200 Kg.-M. (49 665 foot-pounds) in goods service,

in other words one virtual tonne-kilometre will correspond to a resistance of :

5.2 kgr. per tonne in passenger service, and

4.2 kgr. per tonne in goods service *(one virtual Engl. ton-mile will correspond to a resistance of 11.46 lb. per ton in passenger service, and 9.26 lb. per ton in goods service).*

Calculations of this kind have already been made in Germany by Hammer in 1931, then by Landsberg, member of the Management Committee of the German State Railways, in 1916 and 1927; it is interesting to point out that the figures given by the latter author differ little from those given above.

Figures adopted by Landsberg :

5 200 Kg.-M. (61 490 foot-pounds) for passenger services,

4 300 Kg.-M. (50 847 foot-pounds) for goods services.

Taking as a first approximation the values of 5 200 and 4 200 Kg.-M. per tonne-kilometre in fast and slow goods services, we have been able to determine the total amount of work corresponding to the slow and fast traffic worked in 1929 by each French railway system; by comparing the total of these two amounts of work with the fuel consumption of these railways (deducting the consumption in the shunting service) we have

found the following approximate efficiencies [1]:

2.3 on the French State,
2.4 on the Alsace-Lorraine,
2.5 on the Nord,
2.8 on the Est,
2.5 on the Paris-Lyons-Mediterranean,
2.4 on the Paris-Orleans,
2.2 on the Midi.

The above figures are only a matter of magnitude, as I would repeat the values for the useful work per gross tonne-kilometre hauled in goods service are certainly greater on the State, Paris-Orleans and Midi, owing to the nature of the loading, than on the Est, Nord and Alsace-Lorraine; the real efficiencies therefore should differ less one from the other than indicated above. The efficiency on the Est is in reality overestimated, and that of the State, Midi and Paris-Orleans underestimated.

I think nonetheless that the average efficiency of steam traction, measured at the drawbar hook is under present conditions between 2.3 and 2.7 for the different railway systems.

Proceeding as we have done we have taken as losses the consumptions of fuel when running light — double headed — assisting, etc. These average efficiencies would be decreased by about 10 % if the consumption in shunting service is also added to these losses.

Efficiency at the tread. — It is possible to calculate the efficiency at the driving wheel treads of the locomotives by taking the values of the resistances given in the above table for the locomotives. The average efficiencies found therein vary between 3.8 and 4 %, according to the railway. The calculation is much more indefinite than for the efficiency at the drawbar hook as the kilometric tonnages corresponding to the locomotives in fast and slow service are not known exactly and the distribution to be made between the two services is in accordance with acceptable hypotheses, but not from properly prepared statistics. Moreover it must not be forgotten that, as we have said before, the resistance at the tread considered here is not exactly the same as that defined by the formulæ of Strahl or Sanzin. This question is at the present time under in-

(1) Without entering into the details of the calculations, we may say that for the following proportions of fast and slow traffic with mean overall consumptions of 50 and 60 gr. of coal, at 7 500 calories, per gross tonne-kilometre hauled (46.14 and 55.36 drams of coal [13 500 B. T. U. per lb.] per Engl. gross ton-mile hanled) the following efficiencies are obtained :

Efficiency corresponding to 50 and 60 gr. of 7 500-calorie coal per gross-tkm. hauled [46.14 and 55.36 drams of coal] (13 500 B. T. U. per lb.) per Engl. gross ton-mile hauled.

Proportion of fast and slow traffic . . .	1/1	1/2	1/3	1/4
Average useful work, in Kg.-M. per gross tonne-kilometre (in foot-pounds per gross ton-mile) hauled	4 700 *(55 577)*	4 533 *(53 602)*	4 450 *(52 651)*	4 400 *(52 030)*
Efficiency as a percentage for 50 gr. per gross ton-km. (46.14 drams per Engl. ton-mile)	2.94	2.84	2.79	2.76
Efficiency as a percentage for 60 gr. per gross tonne-km. (55.36 drams per Engl. ton-mile)	2.45	2.36	2.32	2.30

vestigation in the different testing plants and it will only be possible to make an exact calculation when we are in possession of further experimental results.

Utilisation of steam locomotives.

All those who have not closely followed the work of the depots may be suprised at the differences existing between the average efficiency in ordinary working that we have given and the efficiency at constant load or at variable load found during tests.

This difference is due to the very small average user of steam locomotives, which only work on the average 4 1/2 hours per day during each period in steam of 6 to 10 days, according to the quality of the water. If, as is done in electric power stations, the user of a heat apparatus is defined by the ratio of the work actually produced to that which it could produce if it were constantly worked at its nominal power (during the time that it is available) we find that the average user of a steam locomotive is about 9 % (6 to 12 % according to the working).

Its average user in time is about 18 % and its user in power (during the period of running) is of the order of 30 %. According to the nature of the services this user varies, but it is only in special workings that appreciably higher user of the power is reached.

This user as regards power can be calculated by dividing for each class of locomotive the total consumption in running, first of all by the number of hours in service and then by the grate area of the engines of the series : in this way we get for the French railways rates of combustion varying between 120 and 240 kgr. per hour per m² (24.6 and 49.2 lb. per hour per sq. foot) of grate area, i. e. 30 to 60 % of 400 kgr. (81.9 lb. per sq. foot) per hour if we adopt the convention of taking this latter figure to define the nominal power of the engine.

For users of this order the variation of consumption or of efficiency is relatively great for a small increase of user. This explains why in practice on the railways it is noticed that the effect produced on the consumption by an improvement in the organisation of the service is much greater than that resulting from improving the stock.

This fact, well-known by operators, has led them to define in the most minute details the working of each locomotive and each set of men and to extend gradually double and triple manning, and even in certain cases pooling the locomotives.

Evolution of the operating conditions of the railways.

It would be relatively easy to follow the evolution of the average practical efficiency of steam traction on the railways if the operating conditions had remained the same as before the war; but actually nearly all the European railways have adopted during the last ten years a method of operating like that followed for a long time in America, consisting in increasing systematically the load hauled but leaving the number of trains almost unchanged.

It might be believed that, to fight road competition, the railways would increase the frequency of passenger services and diminish that of the goods trains. Actually only one railway, the Midi, has profited by its electrification to increase the number of passenger trains by 30 % in three years : this policy appears to have been crowned with success since the frequentation, i. e. the average number

of passengers per coach, was in 1929 still the same as on the other railway systems.

Actually in the case of passenger services, the number of passenger trains is smaller than in 1913 on three railways, and slightly greater on three others, and the average weight of the trains has only increased because of the progressive replacement of wood coaches carried on two pairs of wheels, by bogie vehicles with metal bodies. The average number of passenger vehicles per train has remained between 6 and 8 on all railways, except the Paris-Lyons-Mediterranean, where it has increased to 13; the average frequentation, from 15 to 18 passengers, on the 6 railways, falls through this factor to 8 on the Paris-Lyons-Mediterranean.

In the United States neither the number nor the average composition of passenger trains has not varied very much for twenty years : the number of train-kilometres of this class which reached 880 millions in 1910 barely amounted to 900 millions in 1929 (546 820 000 train-miles in 1910 and 559 240 000 in 1929) in spite of an increase of length of the railway system of 10 %. The maximum movement of trains in passenger service was reached in 1926 with an annual distance of 940 million km. (584 100 000 train-miles) i. e. about 6.3 trains per day on the average. As to the average number of vehicles per train, this has remained almost constant, about 6.

In the case of goods services, the number of trains has changed very little in France from 1913 to 1930, but the average weight of the trains has doubled on certain railways; naturally this policy has been more rigourously followed in the United States where the number of goods trains has diminished by 17 % in twenty years (1910 to 1930), in spite of an increase of the kilometric tonnage hauled, of 51 % during the same period. The average daily number of goods trains was about 4 in 1930.

From 1920 to 1930, i. e. in ten years, the gross tonnage hauled on the average on American goods trains has risen from 1 320 to 1 700 tons, while the useful load has increased from 640 to 710 tons.

All locomotive, boiler and steam engine improvements have been made use of to increase the available power at the drawbar hook; the weight of the engines and the grate areas have been considerably increased with this object, naturally much more quickly in America than in Europe, no restrictive influence existing overseas, either as regards braking or weakness of couplings, the continuous brake and very strong central coupling having been adopted long ago in the United States.

All the characteristic aspects of an evolution of rail transport which has taken the same direction in Europe and in America ought to be more strongly marked in the United States; it should moreover be much more clearly visible in the statistics drawn up by the Interstate Commerce Commission as these are much more complete than the official French statistics, and deal with a much greater system of lines [about 400 000 km. (248 500 miles) and 162 railways in America (1) as compared with 42 000 km. (26 100 miles) and 7 railways in France].

Coal consumption per locomotive-kilometre.

Let us consider first of all the consumption of fuel related to the locomotive-kilometre, that we can deduce from

(1) First class railways having annual receipts exceeding $ 1 000 000.

the general statistics got out since 1921 in the United States, i. e. since the time when the American railways, operated by the State during the War, were returned to their owners.

The table below gives for each year from 1922 to 1930 the value of the consumption per locomotive-kilometre in goods, passenger, mixed, shunting and departmental service.

UNITED STATES.

Consumption of coal per locomotive-kilometre

(*per locomotive-mile*).

Year.	Average.	Goods service.	Passenger service.	Mixed service.	Shunting service.	Departments.
	Kgr. per locomotive-km. (*Pounds per locomotive-mile.*)					
1919	48.6 (*172.4*)	69 (*244.8*)	31 (*110.0*)	40.5 (*143.7*)	37.4 (*132.7*)	34 (*120.6*)
1920	59 (*209.3*)	72.5 (*257.2*)	33 (*117.1*)	44.5 (*157.9*)	38.5 (*136.6*)	34 (*120.6*)
1922	48.5 (*172.1*)	68 (*241.3*)	30.5 (*108.2*)	40 (*141.9*)	38.5 (*136.6*)	35 (*124.2*)
1923	46.7 (*165.7*)	56 (*198.7*)	39.3 (*139.4*)	41 (*145.5*)	38.5 (*136.6*)	36 (*127.7*)
1924	47.6 (*168.9*)	68 (*241.3*)	30 (*106.4*)	41 (*145.5*)	39.0 (*138.4*)	36 (*127.7*)
1925	46.0 (*163.2*)	67.5 (*239.5*)	28 (*99.3*)	40.2 (*142.6*)	38.9 (*138.0*)	35.5 (*125.9*)
1926	47.0 (*166.7*)	67.5 (*239.5*)	29 (*102.9*)	39.2 (*139.1*)	39.5 (*140.1*)	36.5 (*129.5*)
1927	46 (*163.2*)	68.5 (*243.0*)	28.6 (*101.5*)	39 (*138.4*)	37.0 (*131.3*)	36.2 (*129.5*)
1928	46 (*163.2*)	66.5 (*235.9*)	28.5 (*101.1*)	39 (*138.4*)	37.2 (*132.0*)	35.5 (*125.9*)
1929	47 (*166.7*)	67 (*237.7*)	29 (*102.9*)	39.2 (*140.5*)	36.6 (*129.8*)	36.5 (*129.5*)
1930	45.6 (*161.8*)	65 (*230.6*)	28.5 (*101.1*)	38.3 (*135.9*)	36.0 (*127.7*)	34.5 (*122.4*)

This table shows that ignoring the violent increase of consumption which took place throughout the world in 1920-1921, the working of the American railways was carried out for each class of trains at practically constant fuel consumption per locomotive-kilometre, the specific consumption, consumption per gross tonne-kilometre hauled, decreasing approximately as the load increases.

Though the official French statistics do not enable us to make so complete a comparison service by service, we can find for each railway system the value of the average consumption per locomotive-kilometre for the whole of the services; as in each railway system the proportion of passenger traffic relatively to the goods traffic has remained sensibly the same (except in 1920-1921), the average results are comparable from one year to another. From railway to railway, the comparison is more difficult precisely because the proportions of passenger and goods traffic are very different; they vary from 0.39 for the Alsace-Lorraine system to 1.56 for the State, passing from

0.48 for the Est, 0.53 for the Nord, 0.72 for the Paris-Lyons-Mediterranean, 0.80 for the Midi, and 1 for the Paris-Orleans.

The table below gives for the different French railways the consumption per locomotive and per kilometre (and per mile) for the whole of the passenger and goods services.

FRENCH RAILWAYS.

Average coal consumption per locomotive-kilometre

(*Per locomotive-mile.*)

Year.	Nord.	Est.	Paris-Orleans.	P. L. M.	Midi.	State.	Alsace-Lorraine.
	Kgr. per locomotive-km. *(lb. per locomotive-mile).*						
1913. . . .	16.05 (*56.94*)	14.79 (*52.47*)	16.03 (*56.87*)	14.74 (*52.29*)	14.03 (*49.77*)	13.8 (*48.96*)	16.85 (*59.78*)
1921. . . .	21.45 (*76.10*)	20.45 (*72.55*)	22.18 (*78.69*)	22.43 (*79.58*,	19.33 (*68.58*)	22.4 (*79.47*)	22.48 (*79.75*)
1922. . . .	19.91 (*70.64*)	19.78 (*70.18*)	20.80 (*73.79*)	21.32 (*75.64*)	17 81 (*63.18*)	21.99 (*78.02*)	22.72 (*80.61*)
1923 . . .	19.66 (*69.75*)	19.24 (*68.26*)	20.97 (*74.40*)	20.65 (*73.26*)	17 77 (*63.04*)	21.81 (*77.38*,	22.53 (*79.90*)
1924 . . .	19.96 (*70.81*)	18.89 (*70.56*)	20.80 (*73.79*)	21.28 (*75.50*)	17.18 (*60.95*)	21.51 (*76.31*)	22.59 (*80.14*)
1925. . . .	19.89 (*70.56*)	18.60 (*65.99*)	20.24 (*71.81*)	21.18 (*75.14*)	16.67 (*59.14*)	21.48 (*76.21*)	21.76 (*77.20*)
1926. . . .	19.87 (*70.49*)	18.77 (*66.59*)	21.14 (*75.09*)	20.59 (*73.05*	17.27 (*61.27*)	22.00 (*78 05*)	22.39 (*79 43*)
1927. . . .	19,37 (*68.72*)	18.27 (*64.82*)	20.26 (*71.88*)	18.98 (*70.88*)	17.34 (*61.52*)	21.19 (*75.18*)	23.31 (*82.70*)
1928. . . .	19.32 (*68.54*)	18.36 (*65.14*)	19.85 (*70.42*)	18.82 (*66.77*)	17.30 (*61.38*)	20.99 (*74.47*)	23.68 (*84.01*)
1929. . . .	19.60 (*69 54*)	19.66 (*69.75*)	19.75 (*70.07*)	19.74 (*70.03*)	17.77 (*63.04*)	21.29 (*75.23*)	24.75 (*87.81*)
1930. . . .	19 60 (*69.54*)	19.43 (*68.93*)	19.92 (*70.67*)	19.27 (*68.36*)	17.90 (*63 50*)	21.08 (*74.79*)	
1931. . . .	19.60 (*69.54*)	19.10 (*67.76*)	19.58 (*69.46*)	19.21 (*68.15*)	17.80 (*63.15*)	21.21 (*75.25*)	

This table and the diagram figure 6 show that in France, as in America, the working automatically regulates itself to constant coal consumption per locomotive-kilometre for a given locomotive stock. Before the war on each railway system with the then existing stock of engines the consumption per locomotive-kilometre varied slowly and increased progressively at the same time as the average power of the stock, a power which can be characterised by the average value of the grate area $G_m (G_m = \frac{\Sigma nG}{\Sigma n}$ n being the number of engines in the stock having the grate area G).

From 1916 to 1920 the composition of the locomotive stock changed much more suddenly than at any other period in railway history, and after the war the consumption per locomotive-kilometre became fixed at a value of about 20 kgr. (71 lb.) on the Paris-Orleans Railway, a value about 30 % higher than that of 1914 because the average grate area of the engines in the locomotive stock had increased from 2.1 m² in 1914 to 2.7 m² after the war (22.6 to 29.06 sq. feet) and that $2.7 = 2.1 \times 1.30$.

Obviously many influences affect this consumption, such as the quality of the coal, user of the rolling stock, user of

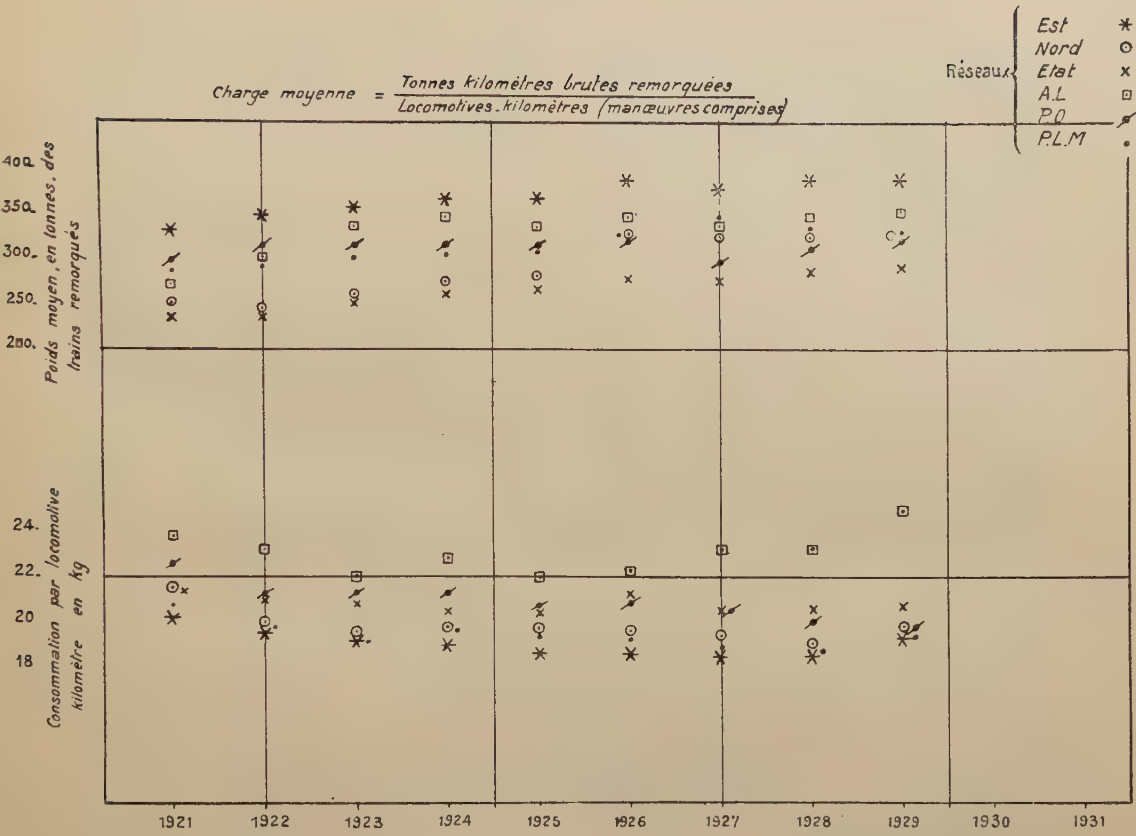


Fig. 6. — French Railway Systems. — Coal consumption per locomotive-kilometre and average load hauled per locomotive from 1921 to 1931.

Explanation of French terms:

Charge moyenne, etc... = Average load = Gross tonne-kilometres hauled / Locomotive-kilometres (shunting included). — Consommation par locomotive-kilomètre en kg. = Consumption per locomotive-kilometre in kilogrammes. — Poids moyen, etc... = Average weight in tonnes of the trains hauled.

the staff, speed of the trains; but the war experience of nearly all the railway companies of the world seems to lead to the conclusion that the practical maximum efficiency of a given locomotive stock is expressed by a definite coal consumption per locomotive-kilometre.

This consumption depends for each service upon the power of the engines used, a power which we will characterise in virtue of the principle of mechanical similarity which appears to be particularly applicable to steam locomotives by the average grate area of the stock.

Average coal consumption per square metre of grate area and per locomotive-kilometre.

Now that we have come to this point it is natural to endeavour to ascertain

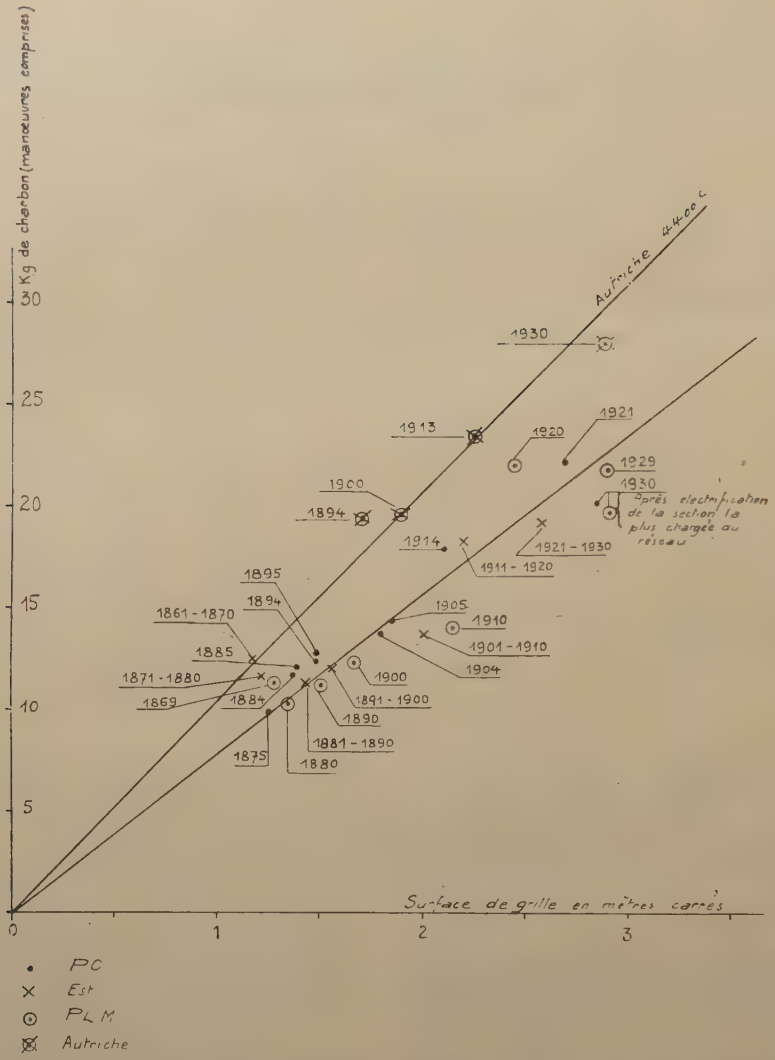


Fig. 7. — Variation of coal consumption per locomotive-kilometre in terms of the average grate area of the locomotive stock.

Explanation of French terms:

Kg. de charbon, etc. = Kgr. of coal (shunting included). — Surface de grille, etc. = Grate area in square metres. — Après électrification, etc. = After electrification of the busiest section of the line.

how the consumption per locomotive-kilometre in terms of the average grate area of the stock of engines has varied in the course of time. On the diagram of figure 7 we have brought together the information which we have been able to collect with the assistance of our colleagues, for the four railway systems :

the Est, Paris-Lyons-Mediterranean, Paris-Orleans and Midi.

This diagram shows that the average coal consumption per locomotive-kilometre varies nearly proportionally to the grate area. Obviously this proportionality can only be approximate, the conditions of operation of the different railway systems having widely varied during the last fifty years, especially as concerns the proportion of passenger and goods traffic.

Our investigation would have been much more interesting and more thorough if instead of the average total consumptions of each railway system we could have investigated separately the evolution of the consumption per square metre and per kilometre in passenger service and in goods service.

However this may be, the coefficient of proportionality for the railway systems considered is on the average 7.6 $\left[\frac{20 \text{ kgr./km.}}{2.6 \text{ m}^2.} = 7.6 \text{ kgr.m}^2\text{/km.}\right.$ (2.50 lb. per sq. foot of grate area and per mile)].

The points relative to the French Midi Railway, supplied some time after the diagram in question had been prepared, fall almost exactly on the straight line C/Loco.-km = 7.6 G.

	MIDI RAILWAY.	
	1913	1931
Average grate area, m^2 (*sq. feet*)	1.8 (*19.4*)	2.33 (*24.8*)
Average coal consumption. kgr. per locomotive-kilometre (*lb. per locomotive-mile*)	14.03 (*49.77*)	17.77 (*63.04*)
Average coal consumption, kgr. par m^2 of grate area and per km, (*lb. per sq. foot of grate area per mile*). .	7.8 (*2.57*)	7.6 (*2.50*)

A very interesting comparison with the Swiss Railways has been made by using the very complete statistics prepared by the Federal Railways during the last 30 years. If for services worked by steam in 1913 and 1931 we calculate on the one hand the average coal consumption per kilometre and on the other hand the average grate area, we find :

	SWISS FEDERAL RAILWAYS.	
	1913	1931
Average grate area, $G_m = \frac{\Sigma n G}{\Sigma n}$, m^2 (*sq. feet*)	2.12 (*22.8*)	2.41 (*25.8*)
Average consumption, kgr. per locomotive-kilometre (*lb. per locomotive-mile*)	14.97 (*53.11*)	17.0 (*60.31*)
Consumption, kgr. per m^2 of grate area and per km. (*lb. per sq. foot of grate area and per mile*) . . .	7.06 (*2.33*)	7.05 (*2.32*)

The coincidence between these figures and those obtained in the case of the Paris-Orleans Company in 1930 : $\frac{20}{2.8} = 7.1$ is very striking.

On the same diagram we have shown the operating results in Austria which we owe to the kindness of Mr. Seefehlner. In Austria the characteristics of the locomotives are slightly different from those of the French locomotives, owing to the quality of the coal used. Taken in coal at 4 400 calories (7 920 B. T. U. per lb.), the consumptions are those given on the figure; we see that the four points representative of the results supplied also fall practically on a straight line.

As we have no information upon the grate areas of the American locomotives, we have not been able to ascertain the value of the coefficient of proportionality for each service; we have however been able, thanks to the kindness of the Engineers of the Pennsylvania Railroad, to form an idea of the magnitude of these coefficients for the goods and passenger services.

The operating results of the Pennsylvania Railroad are given in the table below :

	PENNSYLVANIA RAILROAD	
	Passenger service.	Goods service.
Average grate area, m² (*sq. feet*)	5.6 (*60.3*)	5.82 (*62.4*)
Coal consumption, kgr. per locomotive-kilometre (*lb. per locomotive-mile*)	31 (*109.9*)	72 (*255.4*)
Coal consumption, kgr. per m² of grate area and per km. (*lb. per sq. foot of grate area and per mile*)	5.5 (*1.81*)	12.4 (*4.1*)

The average value of the coal consumption per kilometre and per square metre of grate area for an approximate proportion of 90 % between the number of goods and passenger locomotives, as exists on the Pennsylvania Railroad, is :

$$\frac{124 \times 0.90 + 5.5}{1.90} = 8.8.$$

(2.34 lb. per sq. foot of grate area per mile).

This figure is much higher than that obtained on the French railways, the conditions of user of the American engines being quite different from those in France, the mean rate of coal fired on the grates being for average speeds of about 25 and 60 km. (15.5 and 37.3 miles) in goods and passenger services :

$5.5 \times 60 = 330$ kgr./m²/h. (67.6 lb. per sq. foot per hour), and

$12.4 \times 25 = 310$ kgr./m²/h. (63.5 lb. per sq. foot per hour).

These average rates are much higher than those usual in Europe. The coefficient of average coal consumption per square metre of grate and per kilometre also appears to be directly influenced by the rate of combustion, and by the mean overall efficiency. The mean efficiency at the drawbar hook should be barely 2 % in the United States, the average running resistance of the heavy

Curves of the yearly variation of the weight of the train.

.... Not including the weight of the engines.
+++++ Including the weight of the engines.

Curves of yearly variation in the specific consumption per gross tonne-kilometre hauled.

- - - - - - - - Not including the weight of the engines.
———— Including the weight of the engines.

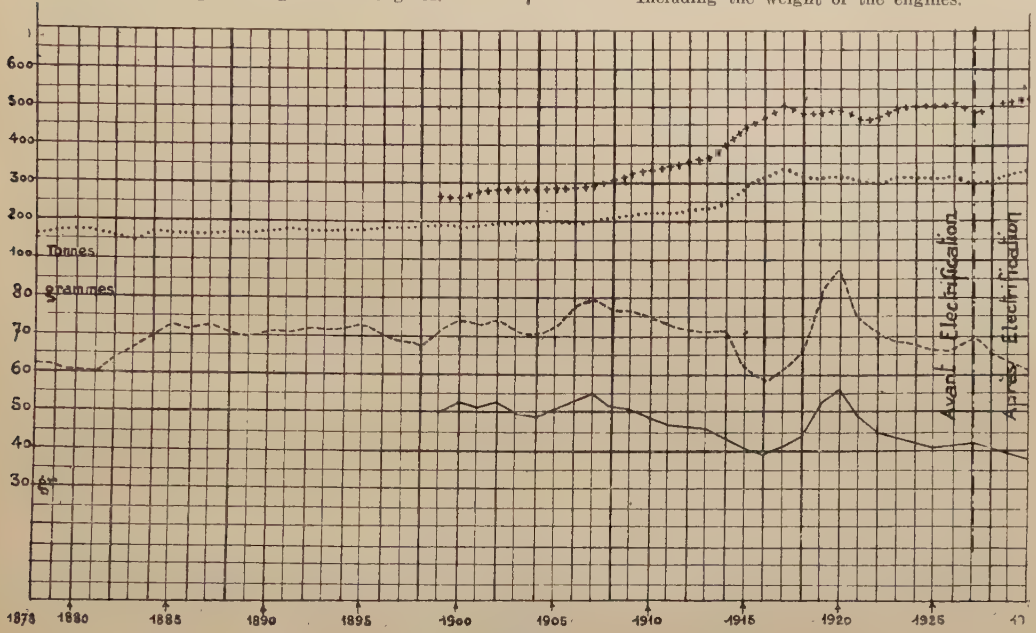


Fig. 8.

Note : Avant (après) électrification = Before (after) electrification.

wagons used in the United States in goods trains not exceeding 1.5 kgr. (3.3 lb.) per ton.

Specific average consumption per gross tonne-kilometre hauled.

The diagram in figure 8 shows the variations of the specific consumption per gross tonne-kilometre hauled and per tonne-kilometre (locomotive included) of the Paris-Orleans Railway from 1878 to 1930; we have also indicated the variations in the average weight of the train, engine included, and engine excluded.

In order to follow the evolution of the methods used to cover the service, we have shown in figure 9 the variations of the adhesive weight, of the total weight, and of the grate area of the locomotives in terms of the time.

This diagram shows that immediately after the regrouping of the French railway systems due to the application of the law of the 11 November 1883, the specific consumption increased from 60 to 70 grammes (55.4 to 64.6 drams per Engl. ton-mile hauled) and that it hardly changed between 1864 and 1914, the slight reduction found between 1906 and 1914 coinciding with the increase in the weight of the train allowed by the introduction of new engines in the locomotive stock.

From 1914 to 1915 the specific con-

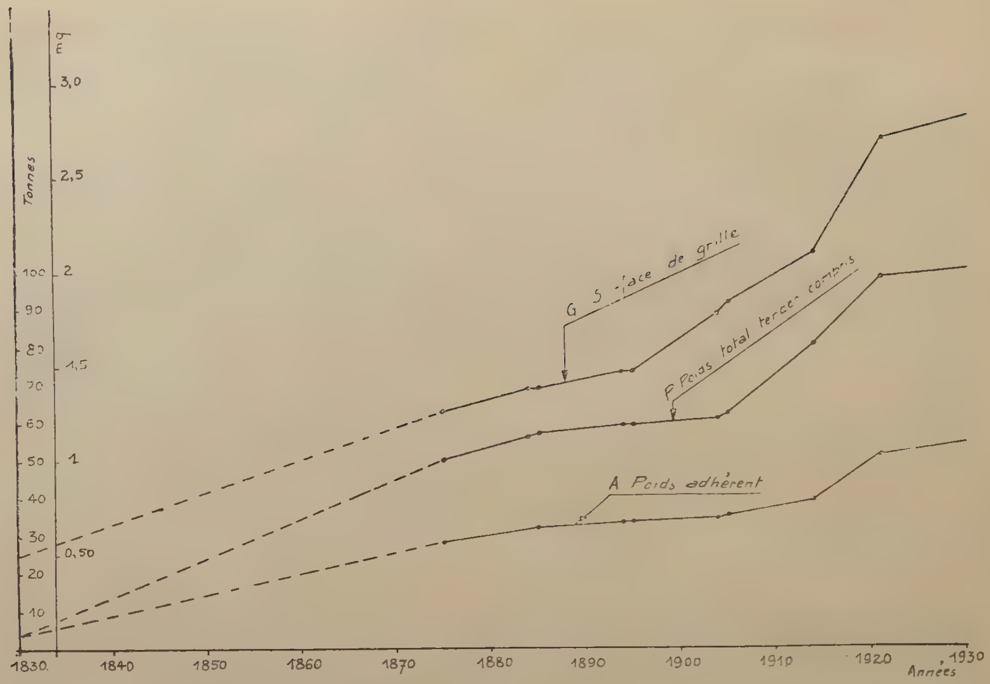


Fig. 9. — Steam locomotives. — Yearly variation of the adhesive weight, of the total weight, and of the grate area. (Paris-Orleans Railway.)

Explanation of French terms:

G = Surface de grille = Grate area. — P = Poids total, tender compris = Total weight, including tender. A = Poids adhérent = Adhesive weight. — Années = Years.

sumption fell very considerably owing to the increase of the load and the reduction of the speed; it rose very markedly from 1916 to 1920 in spite of this reduction of speed through the use of engines with increased grate area and of exaggerated power for the service to be worked, from the fact also of the bad quality of the coal; as soon as the operating conditions returned to normal towards 1922, the specific consumption began to decrease in the same rythm as that noticed in 1906 to 1914, regulated by the progressive increase of the average weight of the trains.

After electrification and the use of engines relatively modern rendered available on the rest of the system, the average weight of the trains was increased in the non-electrified zone and the specific consumption has naturally fallen because of this fact, account being taken of the fact that the proportion of passenger trains which is 79 % on the Paris-Orleans-Vierzon section is only 63 % on the rest of the Paris-Orleans Railway.

The specific consumption continues to fall slowly and it would appear that it should become stable at about 59 grammes (54.4 drams per Engl. ton-mile hauled) when the weight of the trains has been increased to the practical limit of

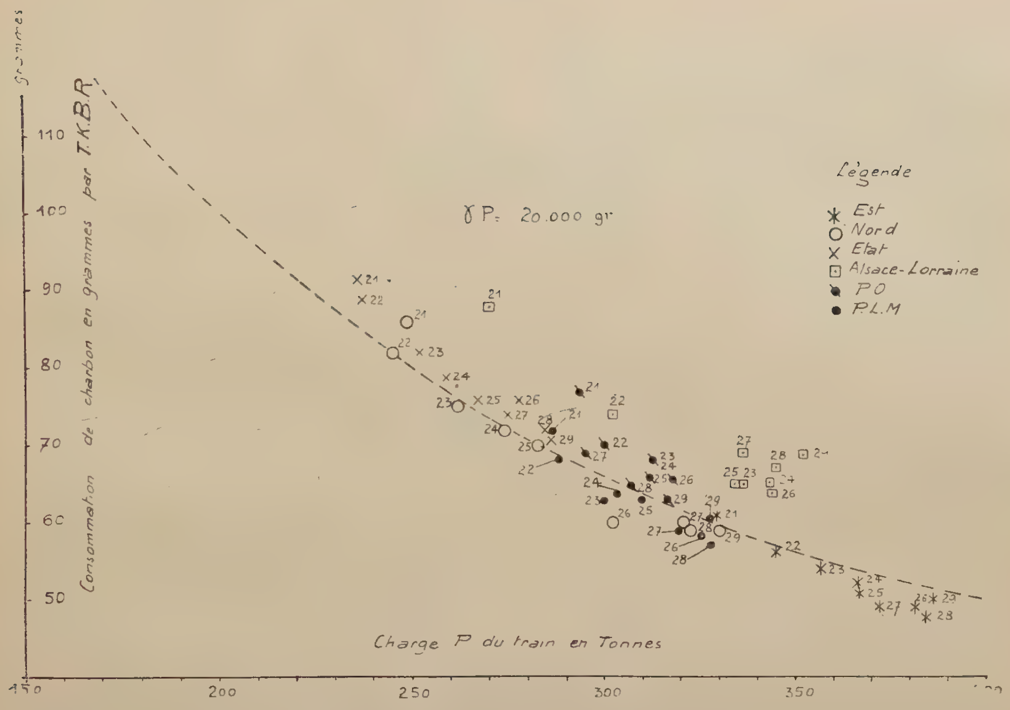


Fig. 10. — Coal consumption per gross tonne-kilometre hauled in terms of the weight of the train. French railways as a whole from 1921 to 1929.

Note : Consommation, etc. = Coal consumption in grammes per gross tonne-kilometre hauled. Charge P, etc. = Load P of the train in metric tons.

the power of the existing stock of locomotives. This figure is of the same order of magnitude as that shown fifty years ago by the same Company.

The diagram (fig. 10) shows the operating results of the French railway systems from 1921 to 1929 by showing as abscissæ the average weight P hauled per locomotive (gross tonne-kilometres hauled divided by the total kilometres run by the locomotives), and as ordinates the specific consumption per gross tonne-kilometre-hauled.

We see that in spite of this variable proportion of the gross tonne-kilometres hauled in passenger and in goods service on the different railway systems, the representative points fall close to the curve γ P = 20 000 grammes. Naturally, except in the case of the Alsace-Lorraine Railways, the corresponding points for the different railway systems having heavy passenger traffic fall above the curve and those corresponding to railways on which the goods traffic preponderates below it.

On the diagram (fig. 11) are shown the operating results for 1913 for the different French railways which lie about the curve γ P = 15 300, lying definitely below the curve γ P = 20 000; the comparison of the curves I and II clearly shows that to haul trains of less than 300 tons the old locomotives [$G_m = 2$ m² (21.5 sq. feet) approximately] are more

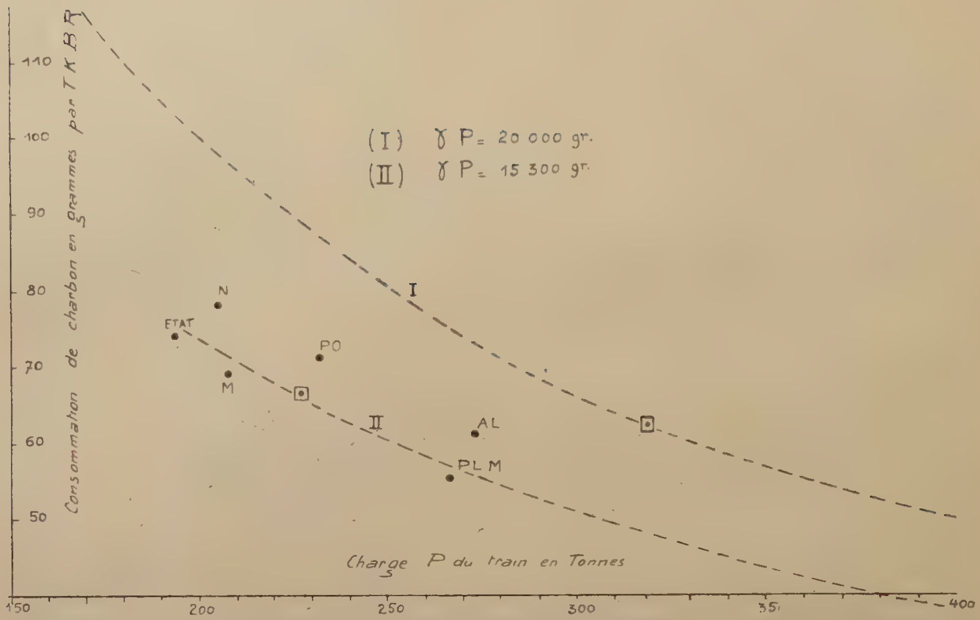


Fig. 11. — Coal consumption per gross tonne-kilometre hauled in terms of the weight of the trains for the year 1913. — French railways.

economical than the new, in spite of the technical improvements that have been incorporated in the latter, whereas for loads of about 400 tons, such as those worked on the Est which the old locomotives are not powerful enough to work, the saving when using more powerful locomotives is indisputable.

The fact which seems self-evident when stated but which many engineers have in practice neglected is that, thanks to the sudden change in the composition of the locomotive stock, a result of the world war, steam locomotives in spite of all the improvements that have been made in them, can only show an efficiency equal or superior to engines considered out of date when they work at a load suited to their dimensions.

Diagram 12 showing the operating results of the Midi Railway illustrates this observation in a very striking manner. This railway system has been electrified since the war systematically and continuously and has obtained in practice the best specific consumption for the weights of trains worked, precisely because on this railway system the movement towards increasing the power of the stock has not been followed.

A more direct explanation of our statement can be found if we refer to our series of constant efficiency curves. For small average powers the efficiency being always low, we see that for each class of engine the average efficiency will be so much the better as the average power used is higher.

The minimum specific consumption will be reached for a stock of steam locomotives, as for a power station, when the average power of the engines is close to the optima power : for a given average power a small machine of small maxi-

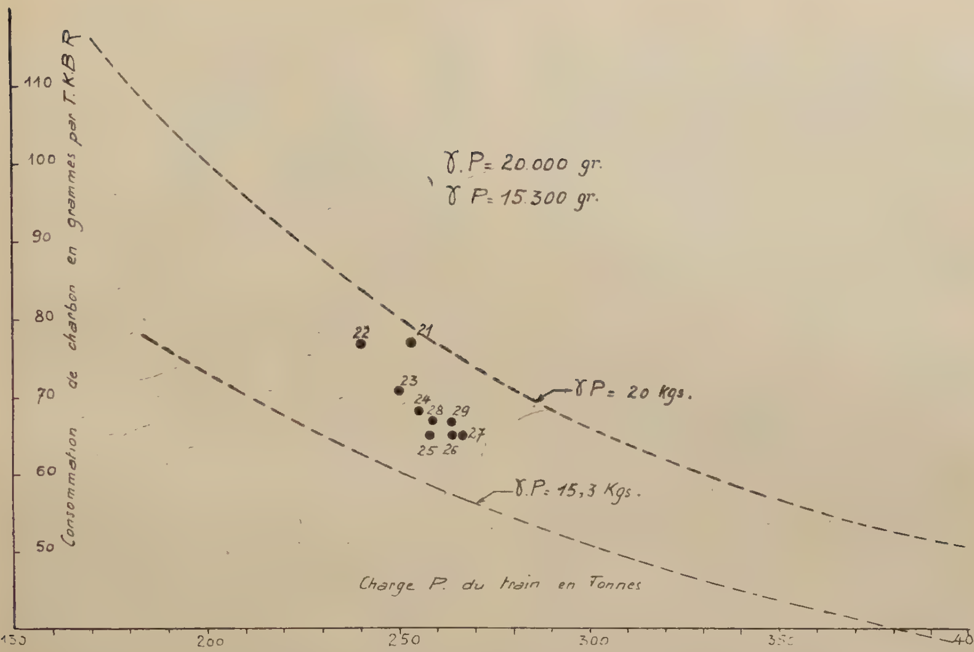


Fig. 12. — Coal consumption per gross tonne-kilometre hauled in terms of the weight of the trains.
Midi Railway, 1921 to 1929.

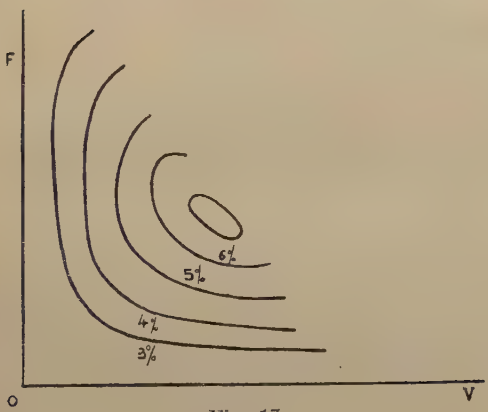


Fig. 13.

mum efficiency can be more economical than a powerful machine with a high maximum efficiency.

This is the same as saying that it is necessary to adapt the power of the tool to the importance of the work to be done, and when a railway system with little traffic wishes to have a stock of locomotives like that of a railway system with heavy traffic it runs a great risk of increasing its expenses out of all measure if it cannot rapidly adjust its operating methods to the power of the equipment it has created.

The importance of this truth does not appear to have been recognised when the railways proceeded to renew their stock by building almost solely powerful locomotives intended for main line working; using onto the lines with little traffic locomotives which were used some years previously for hauling main line trains results in the case of these lines in a

far from negligible reduction of efficiency and this reduces the improvement in the average efficiency of the system. This anomaly tends to become aggravated through the steady increase in the maximum weight of the goods and passenger trains, the proportion between the average weight and the maximum weight of the trains on the railway systems increasing continuously.

This explains why with the traditional movements the average efficiency of steam traction remains at the low value that we have calculated previously.

The curve representing the specific consumption should therefore fluctuate, the ascending portions of the curve corresponding to the introduction of new and more powerful locomotives than the older ones, the descending parts corresponding to the adjustment of the loads hauled to the available power.

In normal times, the fluctuations are hardly visible because the increase of power of the stock and the increase of the weight of the trains take place in a progressive manner. The war by exaggerating the amplitude of the oscillations first of all by a sudden increase in the weight of trains, then by the immense increase in the power of the locomotives, made it possible to analyse the mechanism of these oscillations and to bring out the causes. The examination of the table below giving the average specific consumptions in 1913 and from 1921 to 1931, shows that for certain railway systems, the reduction of the average specific consumption which was very rapid while the average weight of the trains could be increased is now almost arrested; on some railways it has even begun to increase.

Year.	RAILWAY SYSTEMS						
	State.	Alsace-Lorraine.	Nord.	Est.	Paris-Orleans.	P. L. M.	Midi.
	Grammes per gross tkm. (*drams per gross Engl. ton-mile*) hauled.						
1913	75 (*69.2*)	62 (*57.2*)	76 (*70.1*)	67 (*61.8*)	71 (*65.5*)	55 (*50.7*)	69 (*63.7*)
1921	91 (*84.0*)	83 (*76.6*)	86 (*79.4*)	62 (*57.2*)	77 (*71.1*)	72 (*66.4*)	77 (*71.1*)
1922	89 (*82.1*)	75 (*69.2*)	81 (*74.7*)	57 (*52.6*)	70 (*64.6*)	69 (*63.7*)	74 (*68.3*)
1923	83 (*76.6*)	66 (*60.9*)	75 (*69.2*)	54 (*49.8*)	68 (*62.7*)	64 (*59.1*)	71 (*65.5*)
1924	79 (*72.9*)	66 (*60.9*)	73 (*67.4*)	51 (*47.1*)	68 (*62.7*)	65 (*60.0*)	68 (*62.7*)
1925	77 (*71.1*)	66 (*60.9*)	70 (*64.6*)	51 (*47.1*)	66 (*60.9*)	63 (*58.1*)	65 (*60.0*)
1926	76 (*70.1*)	65 (*60.0*)	66 (*60.9*)	49 (*45.2*)	66 (*60.9*)	59 (*54.4*)	65 (*60.0*)
1927	76 (*70.1*)	69 (*63.7*)	60 (*55.4*)	49 (*45.2*)	69 (*63.7*)	59 (*54.4*)	65 (*60.0*)
1928	71 (*65.5*)	68 (*62.7*)	60 (*55.4*)	47 (*43.4*)	65 (*60.0*)	57 (*52.6*)	67 (*61.8*)
1929	72 (*66.4*)	70 (*64.6*)	59 (*54.4*)	50 (*46.1*)	63 (*58.1*)	60 (*55.4*)	67 (*61.8*)
1930	71 (*65.5*)	67 (*61.8*)	59.5 (*54.9*)	50.7 (*46.8*)	61.3 (*56.6*)	52.5 (*48.4*)	69.1 (*63.8*)
1931	70 (*64.6*)	64.4 (*59.4*)	59.3 (*54.7*)	51 (*47.1*)	60 (*55.4*)	52.1 (*48.1*)	67 (*61.8*)

Conclusion.

We do not pretend to have presented any definite results, but only to have indicated the direction in which we should endeavour to improve the accountancy and statistics of the railway systems, as well as the organisation of the premiums and mileage services, in order to arrive at a fuller understanding of the actual operating conditions of the railway systems.

First of all it is desirable to distinguish in the accountancy results and the statistics between the different classes of services, as has been done for a long time in the United States, in order to know exactly the detail cost prices as these are required in order to fix in a rational manner the rates. Whereas a simple consultation of the American statistics reveals that in 1930 the operating cost amounted to :

For goods services, 0.132 fr. per useful tkm. (0.215 French franc per Engl. ton-mile), and for the passenger services, 4.55 fr. per coach-km. (7.44 French francs per coach-mile), the operating coefficient being :

67.65 % for the goods service,
101.22 % for the passenger service, and
74.43 % for the whole of the services,

similar information cannot be supplied for the French railways except by approximations similar to those made by Nadal in his valuable study of 1930 (1).

Using the results of this investigation and transforming them as regards the passenger service, we find that the cost price of rail transport lies, according to the railway system, between 0.10 fr. and 0.17 fr. per useful tonne-kilometre (2) (between 0.1635 fr. and 0.278 fr. per useful Engl. ton-mile), and between 1.90 fr. and 2.70 fr. per coach-kilometre (2) (between 0.306 fr. and 0.435 fr. per coach-mile), the operating coefficient varying from 165 to 200 % for the passenger service and from 55 to 70 % for the goods service.

The useful consumption of energy at the drawbar hook of the locomotives should also be determined periodically in order to obtain through the accountancy returns the average efficiency of steam traction, which is not actually known except by « appreciation »; we think we have shown not only the utility but also the possibility of making these calculations, a reorganisation of the services much less complicated than it would appear at first sight, making it possible to obtain directly each month not only the fuel consumptions and the corresponding efficiencies but also the total cost price depot by depot, line by line, service by service, when operating by steam.

The consideration of the results of tests or of limited trials, interesting though they may and should be, must not make us forget that the expenditure continues to increase in a disquieting proportion on the main line railway systems, and that the search for real savings extends well beyond the narrow field of improvements in detail. Only when the directors of the companies can easily and with certainty ascertain how their systems are actually operated can they take the steps required to meet the present grave situation.

(1) **Annales des Mines**, November 1930.

(2) On the Paris Metropolitan Railway for passenger services with a stop about every 400 metres (every 1/4 mile) in the stations, the same average distance apart, the total cost price is about 3.20 fr. per coach-kilometre (5.15 fr. per coach-mile).

[625. 2 (0]

Use on French and British rolling stock of one-piece doors cast in Alpax,

by Mr. LANCRENON,

Ingénieur en chef-adjoint du Matériel et de la Traction, French Nord Railway.

General considerations.

The question of railway carriage doors has always been very much before the designers.

Whether the door be a hinged or sliding one, its first function is to close the doorway tightly. For this purpose the door has to be light, take up very little room as to thickness, and be of a considerable area, closing up completely the doorway to which it belongs.

This unit is therefore particularly sensitive, by its form, owing on the one hand to the unavoidable vibrations of railway rolling stock, and on the other to the brutal way it is handled by the public either opening or closing it.

In a word, the door is a rigid part constantly called upon to work under shock and vibration.

Secondly, the door frame acts as the support of a series of accessory fittings : runners, handles, locks, hinges, door stops, lights, etc., the fastening of which conditions the construction of the whole unit.

For this reason when making doors of thin plate welded up, an elaborate arrangement of cross bracing to carry these details had to be introduced.

From the double point of view of the general arrangement of the fastening of the fittings, making such a panel with all the stiffness and bosses needed, in the form of a casting in aluminium alloy, provides a solid construction, simple to erect, and costing less.

Thanks to this solid construction, the ordinary running repairs are reduced to the minimum. The same may be said about taking the stock out of service and immobilising the capital represented by it.

The economy obtained in the construction, thanks to the ease of erection, largely compensates for the extra cost of the more expensive metal, and in the event of damage the scrap value represents an appreciable part of the cost of the replace parts.

The design of such a part involves many difficulties, and, to solve in a satisfactory way all the problems that arise, the Engineer has to make full use of all available mechanical facilities.

To get a good hinged door that is both light and easy to work he has to make use of the principle of wedging, and to get satisfactory behaviour in service of the rollers of the sliding doors and the door hinges of hinged doors he has to take into account, in selecting the position of the door stops, the reactions of the points of support.

History of Alpax doors.

The first time a part of this kind was made was on the French Nord Railway, in collaboration with the « Montupet » Foundry in 1922. A door frame

cast in one piece in Alpax was substituted for the wood frame of a hinged door of a third class carriage.

The test was not altogether satisfactory, because the door being too rigid, it did not lend itself like a wood door to deformations of the coach body.

This drawback was easily overcome by hanging the cast door in a frame of the same metal built into the body framing.

An eight-compartment coach involving 16 doors was fitted up in this way in 1923, and has run since that date without anything untoward happening.

This door, moreover, is a straightforward reproduction of the wood door for which it was substituted. A sheet of aluminium held in place by screws replaces the galvanised iron plate over the outside. All the fittings remained unaltered.

The Nord having begun at that period the construction of metal coaches in pressed plate with hinged doors, the turn under of which is very considerable, the question of metal doors again became urgent, as such doors in sheet steel were very difficult to make and the cost was high.

A first test of a chill-cast door in aluminium was carried out by the « Etablissements Métallurgiques de la Gironde » at Bordeaux, and this firm supplied the 22 doors required to fit an 11-compartment 3rd-class carriage [1].

The final design of the metal coaches having been decided upon, the problem of the curved monoblock door in light alloy was taken up by Mr. de Fleury on behalf of the « Forges de Crans » Company and by the « Montupet » Foundry.

Two types of interchangeable doors in cast Alpax were made in three months by these two works in sufficient time to be used on the new mass-produced coaches (figs. 1, 2, 3).

The number of doors of this type in use on the Nord at the present time is 1 500, and they have given excellent results in service.

With all fittings, the Alpax door weighs 60.600 kgr. (133.5 lb.) i.e. 15 kgr. (33 lb.) less than the steel door.

We have here a particularly interesting example of the application of light alloys, because thanks to the saving of labour it has been possible to substitute Alpax for steel and save weight without increasing the cost.

These doors were however relatively heavy and as a result of investigation by the « Coindet » Company it has been possible to lighten them very considerably (figs. 4 and 5).

While the tests were being made in France with hinged doors, the Light-Alloys Company in England manufactured for the Metropolitan Railway sliding doors of a complicated form, cast in Alpax in one piece.

The problem of sliding doors again arose in France when the State Railways were preparing designs for new suburban stock which it was desired should be as light as possible (fig. 6). The space available in the rebates being very restricted, the methods used in making the hinged doors of the Nord were adopted. The door pillars were connected by an ultra-thin sheet reinforced by local thickening. This process very greatly facilitated the feed when casting so thin a piece (fig. 7).

The Nord Railway, which had designed stock of the same type, fitted its first suburban carriages with sliding doors in welded sheet metal.

In view of the results obtained on the State Railways, the Nord decided to fit all future vehicles, the first of which were put into service early in 1932, with Alpax doors (fig. 8).

The doors as supplied by the same makers are a record as regards light-

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[1] Cf. the March 1925 issue of the *Revue de l'Aluminium*.

Figs. 1 to 3. — Hinged doors of 3-rd class metal coaches, French Nord Railway.

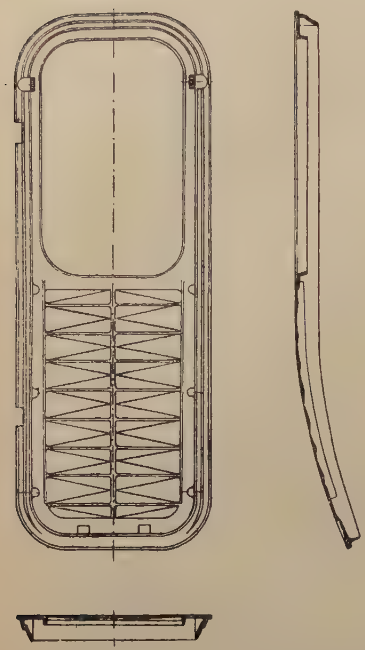


Fig. 1.

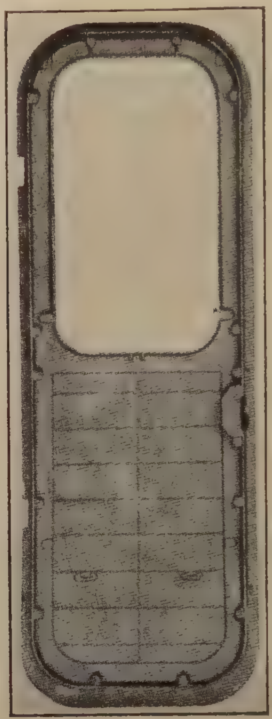


Fig. 2. — Outside panel.

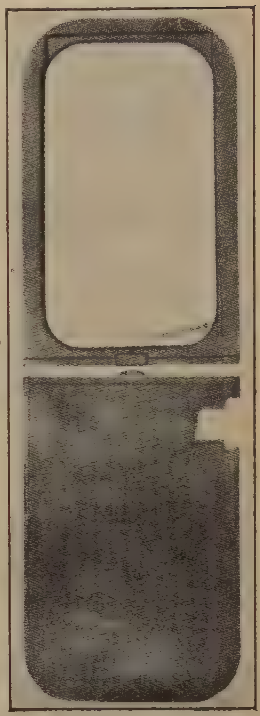


Fig. 3. — Inside frame and panel.

ness, as some of the rough aluminium panels of certain leaves weigh less than 11 kgr. (24.2 lb.), although they are more rigid than the steel doors.

The corrugations acting as feeders have been left visible and the decorative effect, though fortuitous, is satisfactory.

The Paris Metropolitain Railway has also adopted this new type of door which has been perfected by the « Montupet » and the « Saulnier-Duval » Foundries, with the advice of Mr. de Fleury. In this particular case the corrugated panel was replaced by a plain panel. On the other side the bosses were covered by a panel of drawn glass (figs. 9 and 10).

As a matter of information the comparative weights using the different materials are as follows :

A steel door with drawn glass panel weighs.	27 kgr. (59.5 lb.)
An Alpax door with corrugated surface weighs	11 kgr. (24.2 lb.)
An Alpax door with smooth surface w.	15.5 kgr. (34.2 lb.)
An Alpax door with smooth surface and drawn glass weighs	21.5 kgr. (47.4 lb.)

Figs. 4 and 5. — Hinged doors of suburban coaches of the Paris-Lyons and Mediterranean Railway (outside and inside panels).

Fig. 4.

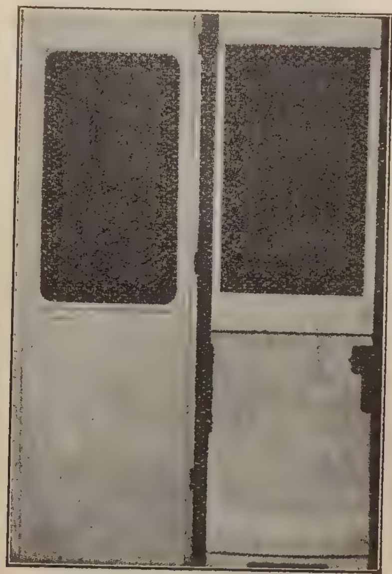


Fig. 5.

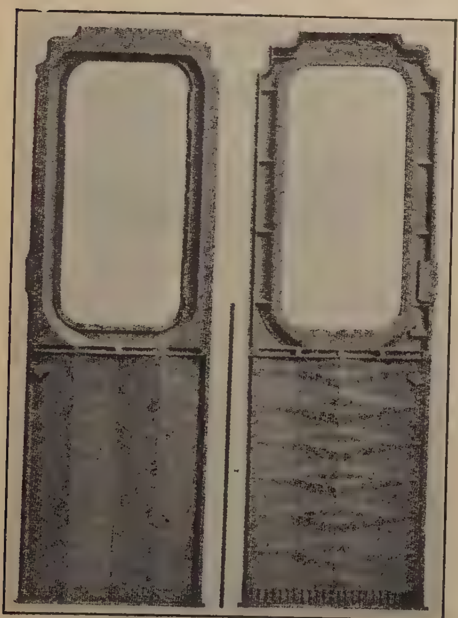


Fig. 6. — Doors of French State Railway suburban coaches (bare leaf).

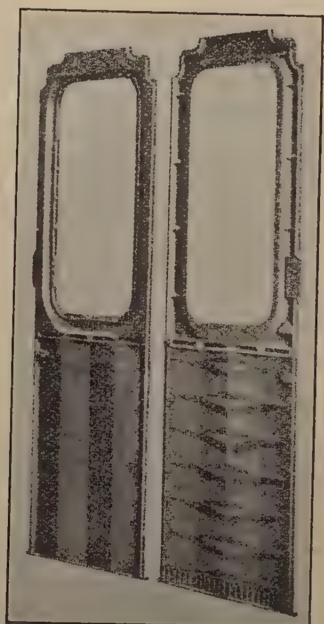


Fig. 7. — Sliding doors of French State Railway suburban coaches.

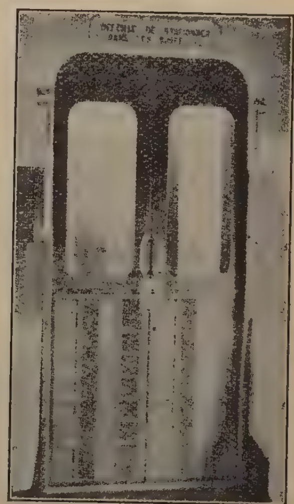


Fig. 8. — Sliding doors of the French Nord Railway suburban coaches.

Fig. 9. — Sliding doors of the Paris Metropolitain coaches (outside).

Fig. 10. — Sliding doors of the Paris Metropolitain coaches (inside).

Comparative data.

1. *Wood doors.* — Wood doors have to be made fairly thick to be sufficiently rigid, otherwise they are too flexible and too prone to get out of shape through wet.

They require careful manufacture and their life is limited.

Outside wood doors are also subject to rot and are not usable in connection with the metal construction of modern vehicles.

2. *Metal doors of steel sheet riveted to a frame.* — Most of the end doors of French and foreign metal coaches are made in this way.

This design is easy to make. But, to make them rigid enough, the outside sheeting has to be made thicker and this means a greater weight. A design of this kind is particularly sensitive to oxidation. Under the repeated shocks to which it is subjected in ordinary service, the parts and rivets become loose, the painting breaks away at these points, and if not made good by very careful maintenance the metal rusts very quickly where the paint has become defective through water getting in.

3. *Metal doors in metal sheet electrically welded.* — This form of construction is even more difficult to carry out than the preceding one.

Two pressings are joined together by welding up their flanged edges. Rigidity is ensured by inside cross bracing spot welded to the two pressings.

Doors made in this way are rigid, thin and light and are more especially suitable for the inside hinged doors of compartments of main line coaches

which have to support relatively small stresses.

4. *Metal doors in light alloy sheet riveted to light alloy framing.* — These doors are lighter than those of the second category but retain most of their shortcomings.

5. *Metal doors in cast Alpax.* — We have shown in chapter II of this article that by very close study of the question, it has been possible to obtain light and strong doors, the cost of which was in certain cases lower than that of the steel door.

This method of construction is in fact definitely profitable in al cases in which the door is difficult to make and in particular when the turn under is considerable, as in the case of the London Metropolitan or in that of the compartment stock of the French Nord. In this case the cast Alpax door is cheaper than the steel.

In the case of the usual flat sliding doors of the Paris Metropolitain type, the extra cost may be estimated at 15 to 20 %, which can easily be recovered on the maintenance side.

The principle of the corrugated wall stiffened transversely by local increases in thickness can be used in place of the riveted or welded box type of construction, with advantage, as it makes it possible to get the minimum average thickness while facilitating the casting of parts of such thinness.

We will end by saying that experience on a large number of French and foreign railways has been entirely satisfactory, and that it has been found that the cost of maintaining doors made in this way may, in practice, be absolutely overlooked.

[625. 2 (0]

Principles of construction of light rolling-stock.

Address by Direktor E. KREISSIG, Uerdingen/Rh.,
before the « Deutsche Maschinentechnische Gesellschaft », 21 April, 1931.

(From *Glasers Annalen*, 1932, vol. 110, Nos. 1315 and 1317.)

The influence of static and dynamic strength, corrosion and corrosion-fatigue, together with the influence of welding on the construction of light vehicles, is discussed and illustrated by examples. Attention is drawn to the necessity for reducing unsprung weight in order to obtain the most efficient design of light construction. Methods are explained and the results of the application of the new principles are demonstrated.

New developments in the construction of light rolling stock relate to matters of technology, manufacture and design, and to the ratio of sprung to unsprung weight.

The construction of light rolling stock received its first impulse by the change over from wood to steel. The saving of weight thus effected was accompanied by an extraordinary increase in the stability of the vehicles, hence the relative gain was several times the absolute saving, for the comparison must be between types equal in service capabilities.

A further possibility of reducing the weight of vehicles resulted from the introduction of new structural steels, by the use of which the German State Railways were able to effect considerable savings of weight in new types of rolling stock.

Alloy steels with improved static properties had long been known, but they were too costly for general use and required, for the full development of their qualities, a heat-treatment which made the manufacture of large pieces a difficult matter. The demand for inexpensive and easily workable steels led to the development of new materials, the superiority of which, compared with the old steels, is shown by the table, figure 1.

—	Ultimate tensile strength, kgr./mm² (*Engl. tons per sq. inch*).	Yield stress, kgr./mm² (*Engl. tons per sq. inch*).	Elongation. %	Fatigue limit, kgr./mm² (*Engl. tons per sq. inch*).
Structural steel St 37	37-44 (*23.5-27.9*)	22 (*14.0*)	22	18 (*11.4*)
Nickel steel	56-65 (*35.6-41.3*)	35 (*22.2*)	18	28 (*17.8*)
C steel	44-51 (*27.9-32.4*)	30 (*19.0*)	20	23 (*14.6*)
Structural steel St 48.	48-58 (*30.5-36.8*)	29 (*18.4*)	18	25 (*15.9*)
Silicon structural steel	50-62 (*31.7-39.4*)	36 (*22.9*)	20	30 (*19.0*)
Union structural steel	56-66 (*35.6-41.9*)	37 (*23.5*)	18	31 (*19.7*)

Fig. 1. — Mechanical properties of various structural steels.

The upper three lines in Table 1 relate to the old, and the lower three lines to three of the newer structural steels. Until recently, steel St 37 was used for the construction of light vehicles, and, to a smaller extent, a C-steel of tensile strength 44 to 51 kgr./mm^2 (27.9 to 32.4 Engl. t. per sq. inch) was also employed. Nickel steel as shown in Table I was restricted to occasional use in bridge building. Comparing the hitherto generally used steel St 37 with the newer structural steels shown in the lower half of Table 1, it will be seen that the St 48 steel, the silicon steel, and the Union structural steel offer a considerable increase in ultimate tensile strength. Moreover, the ratio of the ultimate strength to the yield stress is more favourable in the newer steels than in the St 37 steel, hence the relative increase in yield stress is considerably higher than that in the ultimate strength. There has been a similar improvement in dynamic strength; for example the best of the steels mentioned (the Union structural steel) is about 70 % better than the St 37 steel as regards both yield stress and fatigue limit. It is therefore, at once possible to raise the permissible stress about 70 % in Union steel compared with St 37 steel. Unfortunately, the vehicle builder cannot always make full use of this advantage, because individual components must often be overdimensioned owing to the danger of rusting. For this reason it is important to take the resistance to corrosion, as well as the mechanical properties, as a criterion when comparing the merits of different steels. It has been found that silicon steels are more liable to rusting than other steels, but this tendency can be corrected and reversed by additions of copper.

St 48	36 %
St 48, copper bearing	30 %
St Si	48 %
St Si, copper bearing	12 %

Fig. 2. — Decrease in weight of structural steels after 45 days' exposure to 1% hydrochloric acid.

Figure 2 shows the decrease in weight of various specimens of steel resulting from 45 days' exposure to 1 % hydrochloric acid. A notable feature of this table is the small resistance to corrosion of silicon steel and the high resistance of copper-bearing silicon steel which is, however, exceeded by that of Union structural steel, as shown by the tables, figures 2*a*, 2*b*. The increase in yield stress, together with improved resistance to corrosion, permits the component parts of vehicles to be reduced considerably in weight, nearly if not quite in proportion to the increase in yield stress.

MATERIAL.	Breaking load before corrosion, kgr. (*lb.*)	Breaking load after corrosion, kgr. (*lb.*)	Decrease due to corrosion, %
St 37	3 150 (*6 944*)	2 060 (*4 541*)	35.0
St 48	3 940 (*8 686*)	3 100 (*6 834*)	21.4
St Si	4 000 (*8 818*)	2 950 (*6 503*)	26.3
St Si, copper bearing	4 200 (*9 259*)	3 400 (*7 496*)	19.1
Union structural steel.	4 040 (*8 906*)	3 430 (*7 562*)	14.8

Fig. 2*a*. — Loss of strength of structural steels by corrosion (HC1).

STEEL.	Dynamic strength kgr./mm² *(Engl. tons per sq. inch).*		Decrease,
	Before corrosion	Corroded.	%
St 37	24 (*15.2*)	15 (*9.5*)	37
St 37 (copper bearing)	22 (*14.0*)	17 (*10.8*)	23
St 48	26 (*16.5*)	17 (*10.8*)	35
St 48 (copper bearing)	26 (*16.5*)	19 (*12.1*)	27
Silicon steel	30 (*19.0*)	17 (*10.8*)	43
Union structural steel	33 (*20.9*)	26 (*16.5*)	21

Fig. 2*b*. — Loss of fatigue strength due to corrosion by tap water.

Corrosion does not, however, merely reduce the volume of the material affected; it also reduces its dynamic strength to a marked extent. In this connection, special interest attaches to investigations carried out by Thoma in the mechanical laboratory of the Technische Hochschule, Münich (under Prof. Dr. L. Föppl), and described in the *Zeitschrift des Vereins Deutscher Ingenieure* (V.D.I.), No. 22, 1930. Thoma investigated the behaviour of electric cast steel and rust-resisting cast steel, and found that the action of water on polished test bars resulted in reductions of the fatigue strength to 67 % and 58 % respectively. In the case of a spring steel the fatigue strength was reduced from 76 kgr/mm² to 8.4 kgr./mm² (48.2 to 5.3 Engl. tons per sq. inch), i. e. to 11 % of the original value.

The loss of static strength in structural steels, by corrosion during a certain period, is shown by the data in figure 2*a*; and the reduction in dynamic strength due to corrosion is shown in figure 2*b*. The results in figure 2*a* were obtained by exposing the steels to hydrochloric acid; the extent to which their tensile strength was maintained forms a measure of their resistance to corrosion.

Prolonged investigations of spring steels by the Waggon Fabrik A. G., Uerdingen, indicate that the dynamic strength in tension is considerably different from that in compression. These strengths ranging from zero to a positive or negative maximum are known under the name of « Ursprungsfestigkeiten » (original resistances), and yet the distinct effects of dynamic tension and compression were not known.

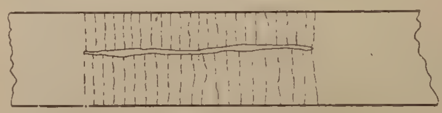
Similar tests were first carried out by

CONDITION OF SURFACE.	Tensile strength.	Yield point.	Original strength		Ratio of original strength in tension and in compression.
			tension.	compression.	
	kgr./mm² (Engl. tons per sq. inch).				
Polished	164.5 (*110.5*)	150.4 (*101.5*)	120 (*76.2*)	165 (*104.8*)	1 : 1.375
Damaged.	162.2 (*102.8*)	143 (*92.8*)	95 (*60.3*)	153 (*97.1*)	1 : 1.611
Polished but corrosion started	160 (*101.6*)	143 (*92.8*)	15 (*9.5*)	157 (*99.6*)	1 : 1.046

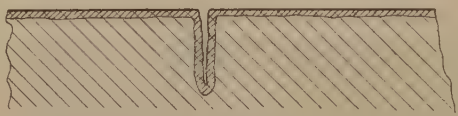
Fig. 3. — Original strengths of spring steel when corroded and under various surface conditions.

the Staatliche Materialprüfungsamt (State Office for testing materials), Berlin-Dahlem, at the request of the Waggon-Fabrik A. G., Uerdingen, and gave the results shown in the table, figure 3.

Three series of tests were made : one with polished bars; a second in which the bars were damaged on the surface by small grooves specially made for this purpose; and a third with polished bars subjected to corrosion. The tensile strength of the bars averaged 162.2 kgr./mm² (102.8 Engl. tons per sq. inch), and the yield stress ranged from 150 to 143 kgr./mm² (95.2 to 92.8 Engl. tons per sq. inch). For the polished bars, the original strength was 120 kgr./mm² (76.2 Engl. tons per sq. inch) in tension, and 165 kgr./mm² (104.8 Engl. tons per sq. inch) in compression. For the bar with damaged surface, the original strengths were 95 kgr./mm² (60.3 Engl. tons per sq. inch) in tension and 153 kgr./mm² (97.1 Engl. tons per sq. inch) in compression. As a result of corrosion, the original strength in tension fell to 15 kgr./mm² (9.5 Engl. tons per sq. inch), but the initial strength in compression was 157 kgr./mm² (99.6 Engl. tons). The ratio of the dynamic tensile strength to the dynamic compression strength was thus 1 : 1.357 in the first, 1 : 1.611 in the second, and 1 : 10.46 in the third case, showing a startling reduction in the tensile compared with the compression strength. These results show that static and dynamic compression strengths are entirely equivalent, that the original strength in compression is not lowered by any of the factors considered, but that the dynamic strength in tension may suffer to a catastrophic extent by damage to the surface of the metal and by corrosion. It is a matter of interest to consider what is the cause of this peculiar phenomenon and how it may be dealt with. Though the causes of corrosion fatigue are not yet fully elucidated, some explanation is afforded by Thanheiser's investigations at the Kaiser-Wilhelm-Institut [1], concerning the formation of blisters on pickled sheets. Thanheiser showed experimentally that the pickling liquid not only dissolves the oxide film but also attacks the sound metal, resulting in the liberation of hydrogen. The nascent hydrogen is in atomic form of so fine a structure that it penetrates into the iron until it reaches a flaw in the plate (fig. 4, upper). Hydrogen entering the cavity changes into the molecular form, meanwhile developing an extremely high pressure. The experiments in question had to be stopped at 300 atmospheres (4 400 lb. per sq. inch) owing to the limitations of the apparatus. The high pressure thus developed dilates the plate, forming a blister.



Diffusion of hydrogen in thin plates.



Saturation of surface film with hydrogen during rusting.

Fig. 4.

It is possible however that similar actions play an important part in corrosion fatigue. Corrosion in so far as it is due to water, is accompanied by the liberation of hydrogen, which diffuses into the outer layers of the iron forming a surface-film saturated with hydrogen (fig. 4, lower). There are cracks in even the most highly polished surface, and the liberation of hydrogen naturally extends to the bottom of the fissure. As saturation with hydrogen makes the material

(1) *Zeitschrift fur technische Physik*, 1929, No. 4, p. 143.

brittle, an extension of the crack occurs at the bottom of the fissure, where the stresses are intensified, and where a brittle film is formed. This is followed by deeper penetration of hydrogen and consequently further cracking. This hypothesis is supported by the fact that mechanical and corrosive influences must act simultaneously in order to produce the catastrophic effects noted.

Technical means of dealing with the problem have not been discovered, to the author's knowledge, with the exception of American experiments, which led to successful results by the use of protective metal coatings. The difficulty can however be overcome to some extent by constructional means, by displacing the stresses towards the compression side.

$$\frac{e_2}{e_1} = \frac{\textit{Original compression strength}}{\textit{Original tensile strength}}$$

Fig. 5. — Cross section of leaf spring.

An example of this is illustrated by figure 5, showing the cross section of a laminated spring, the neutral axis of which is displaced towards the tension side by grooved depressions on the compression side. The ratio of tension to compression can thus be adjusted to the requirements of the material and the service.

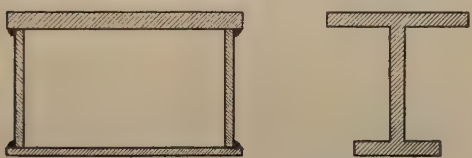


Fig. 6. — Beam sections for different tensile and compression stressing, subject to bending from one side only.

Figure 6 shows the application of the same constructional principle to two beams subject to bending in one direction only. The right-hand figure shows an I-beam, the compression flange of which is narrower than that of the tension flange. Alternatively, both flanges may be of equal width but different thicknesses. The left-hand figure shows a welded box-girder with plates of different thickness for tension and compression.

Where bending occurs in both directions, a different constructional principle must be used, viz. that shown in figure 7 imposing a suitable initial stress on the material. This figure (left) shows a box-girder which is placed under initial compression by a central tie rod. If the beam were subjected to no initial stress, its tensile and compression stresses would be symmetrical in either direction, but when the beam is placed under initial compression by the tie rod, the tension due to bending is reduced and the compression is increased by the initial compression. It is thus possible again to realize the desired ratio between net tensile and compression stresses.

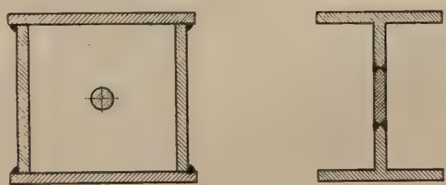


Fig. 7. — Imposition of initial stress on beams, in order to obtain different tensile and compression stresses under bending load.

Figure 7 (right) shows an I-beam made by welding together two tees and a flat as indicated. If the central strip in the web is kept hot during the welding, its subsequent contraction on cooling places the flanges in compression.

From the beams of figure 7 to a rotating axle is but a short step, and figure 8 illustrates the application of the same principle to a hollow railway axle, placed in initial compression by means of a central tie rod.

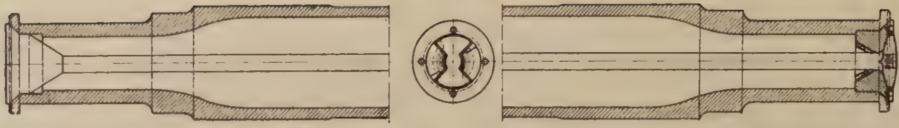


Fig. 8. — Railway axle placed in initial compression by means of a central tie rod.

Welding offers a further possibility of saving in weight, hence the weldability of the material employed is of as fundamental importance as an increase in yield ratio and a greater resistance to corrosion.

An important distinction in the building of rolling stock compared with many other forms of structural work, is that the beams employed are subjected not only to tension and bending but also, in most cases, to torsion and buckling. The only member equal to such conditions is the tube or box-girder. Riveted box-girders are troublesome to build and heavy when finished. Welding, on the other hand, enables box-girders to be used without difficulty, and generally with a considerable saving of weight compared with open sections.

At the same time the box-girder, provided that it is really airtight, is exposed to corrosion only on the outside. The vulnerability of the structure is thus reduced, compared with the flanges and webs of ordinary beams which are exposed to corrosion on both sides.

Again, welding makes possible a smoother construction than can be obtained by riveting, as will be seen by comparing figures 9 and 10. Riveting adds to the weight of the construction by the overlapping of the plates and the necessity for rivet heads. Also, it increases the liability to corrosion. The plates do not fit perfectly on each other, and water penetrates into the gaps, particularly as the paint is not completely impermeable to air and moisture. Rusting is also favoured by the stress between the rivet and the plate, and by the different stresses in the upset rivet shank and the adjoining plate. On the other hand, as shown by figure 10, welding makes possible a smooth construction and, if thermal and other internal stresses cannot be completely avoided, they are at any rate considerably smaller and less dangerous than where riveting is used.

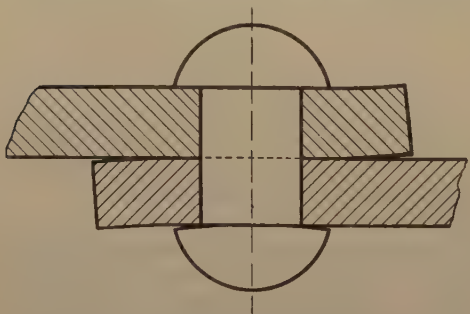


Fig. 9. — Gaping of plate edges in riveted connection.

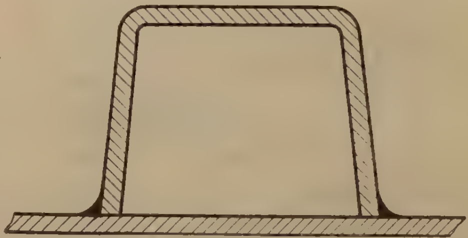


Fig. 10. — Welded box column.

A further advantage of the use of welded beams lies in the fact that provision can be made for the different limiting fatigue ranges in tension and compression by using plates of different thicknesses. The welded beam being, in any case, built up from separate components there is no difficulty in selecting the dimensions of each so as to effect a further saving in weight in

beams subject to bending in one direction only.

In building box-girders care should be taken that the welded joint is subject to minimum stress. Recent investigations on the strength of welds have shown that the weld metal has a relatively high yield stress, nearly equal to the ultimate tensile stress. This is an advantage where static loading is concerned, but

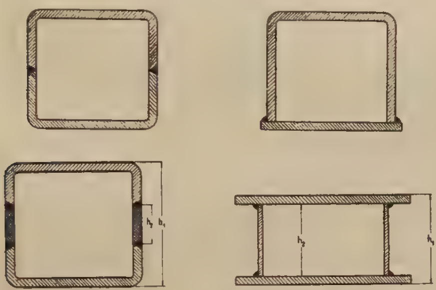


Fig. 11. — Welded beam sections.

there is the disadvantage that the fatigue strength is relatively low. Thus, until other results appear, it is necessary to be very cautious in stressing welded joints and to base designs on a fatigue strength of about 10.00 kgr./mm² (6.35 Engl. tons per sq. inch).

In beams subject to bending, the weld should be on, or as near as possible to, the neutral axis (fig. 11, upper left). Where this is impracticable, the weld should be placed on the compression side (fig. 11, upper right); and this should be done also in the case of beams subject to torsion. In the case of a beam subject to torsion, or to bending and torsion, the weld should not be on the neutral axis but on the compression side of the structure, because compression loading relieves shear. In so far as welded joints on the tension side cannot be avoided, they must be so placed that they are not stressed beyond their permissible carrying capacity. For example, in the case of Union structural steel, the static carrying capacity of the weld is 85 % of the strength of the steel, from which the limits for the location of the welded joint under purely static load can at once be determined.

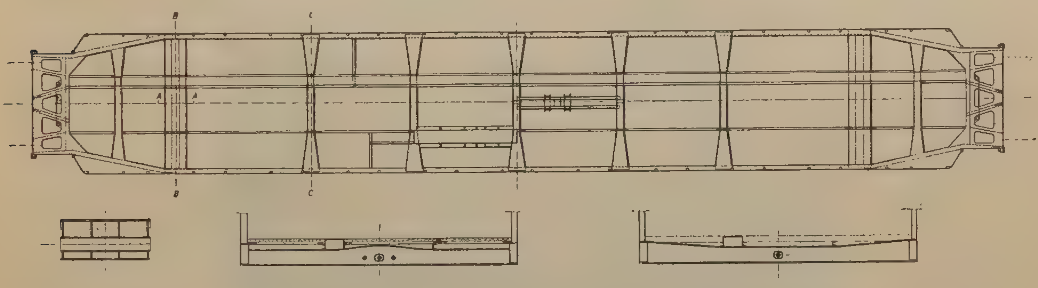


Fig. 12. — Welded box-girder underframe for express train corridor coach.

It is now proposed to consider a number of different welded constructions. Figure 12 shows an underframe for a welded express train corridor coach. The solebars and cross bearers are of box construction, and the cross bearers are approximately beams of uniform strength. In the central portion of the frame, the cross bearers are spaced equally in order to obtain equal buckling and bending lengths in the several sections of the longitudinal bearers or side frames; but the distance between the main cross bearers and the first of the intermediate cross bearers at each end is increased, as justified by the greater moment of inertia of the main cross bearers. The latter are provided with

differently stressed tension and compression plates. The use of box girders, arranged uniformly as explained, imparts to the underframe maximum re-

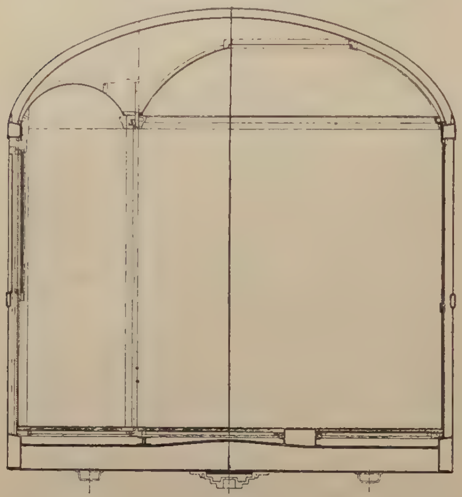


Fig. 13. — Cross section of body of welded express train corridor coach.

silience in a horizontal direction and, at the same time, maximum ability to withstand eccentric and central horizontal forces.

Figure 13 shows the body cross section of the same vehicle. The body sides form one unit with the sole bars, and with the longitudinal box-girder of the roof; these girders are thus connected by the side wall plate and the box columns. The roof supports, columns and cross beams form a portal structure, although they are not in the same planes, the longitudinal beams of the roof and underframe transmitting all moments. Besides a considerable increase in stability, the construction shown in figures 12 and 13 effects a saving of about 4 tons in the weight of steel parts.

Figure 14 shows a welded 20-ton wagon in which very effective stiffening of the sides is secured by the exclusive use of box girders. The upper corners of the sides, adjoining the doors, are particularly liable to be damaged by crane grabs and, in the construction shown, the door edges are stiffened by a box frame consisting of the door posts and a cross beam in the same plane. With the exception of the buffer beams, no other cross bearers are used, the box-type longitudinal girders carrying welded-on brackets for the brake suspensions. The longitudinal girders also

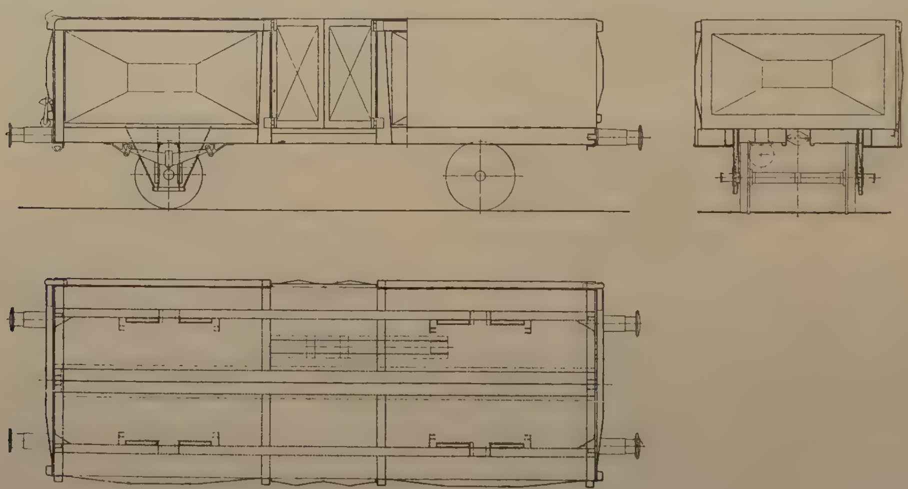


Fig. 14. — Welded 20-ton wagon.

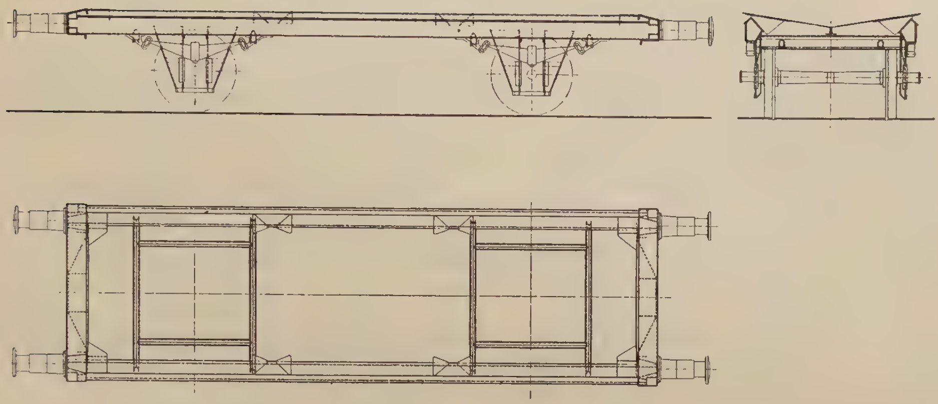


Fig. 15. — Welded underframe for hopper wagon.

take torsional moments resulting from horizontal forces transmitted through the hornblocks, with increased safety compared with earlier constructions.

The underframe shown in figure 15 is intended for a coal hopper wagon, and demonstrates how easily special constructive problems can be solved by

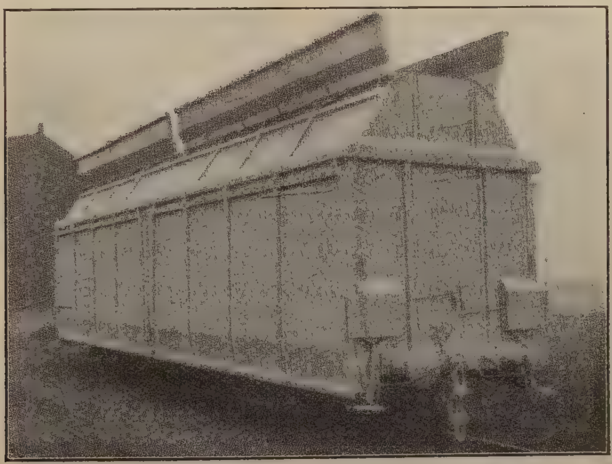


Fig. 16. — All-welded saddle-bottomed wagon of 100 m. (130.8 cubic yards) capacity.

welding. In order to reduce corrosion to a minimum, water draining from the coal must be carried away quickly. For this reason, all the girders have a roof-like, self-draining top (see fig. 15) and are built as box beams. Maximum security against rust is thus combined with maximum stability and minimum weight.

The vehicle shown in figure 16 is a covered saddle-bottomed wagon of 100-m^3 (130.8 cubic yards) capacity. The

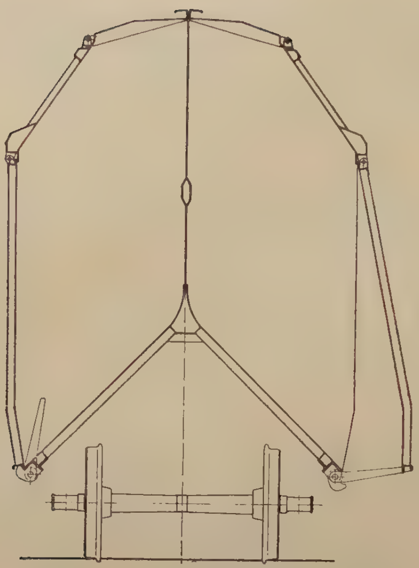


Fig. 17. — Cross section of a welded saddle-bottomed wagon.

openings in each side are closed by two hinged flap doors 6.70 m. (22 feet) in length. Owing to the size of these openings, careful stiffening is required, and box-girders can again be used to advantage as shown in figure 17. The wagon is welded throughout, with the result that a saving in weight of 2 tons is effected and considerably longer life may be expected than from a similar vehicle of riveted construction. Figure 18 shows another view of this vehicle from which further details can be seen.

The preceding constructions relate mainly to the sprung weight, but the reduction of unsprung weight is of more far-reaching importance. The unsprung weight has a destructive effect on the permanent way, and also causes disturbance in the vertical springing of the body.

Figure 19 represents the simplest case

Fig. 18. — Side view of welded saddle-bottomed wagon.

of the movement of wheels and sprung weight, viz. the surmounting of a rigid obstacle of about 15 mm. (5/8 inch) height at a speed of 60 km. (37.3 miles) per hour. The fact that rigid obstacles do not occur in practice does not prejudice the present conclusions concerning the relative effects of sprung and unsprung weight. Figure 19*a* shows the path of the sprung weight, figure 19*b* that of the unsprung weight, and figure 19*c* the vertical speed of the wheel set. Two sets of wheels of 1 200 kgr. and 800 kgr. (2 640 and 1 760 lb.) weight

Influence of unsprung weight on movements of the wheels and body.

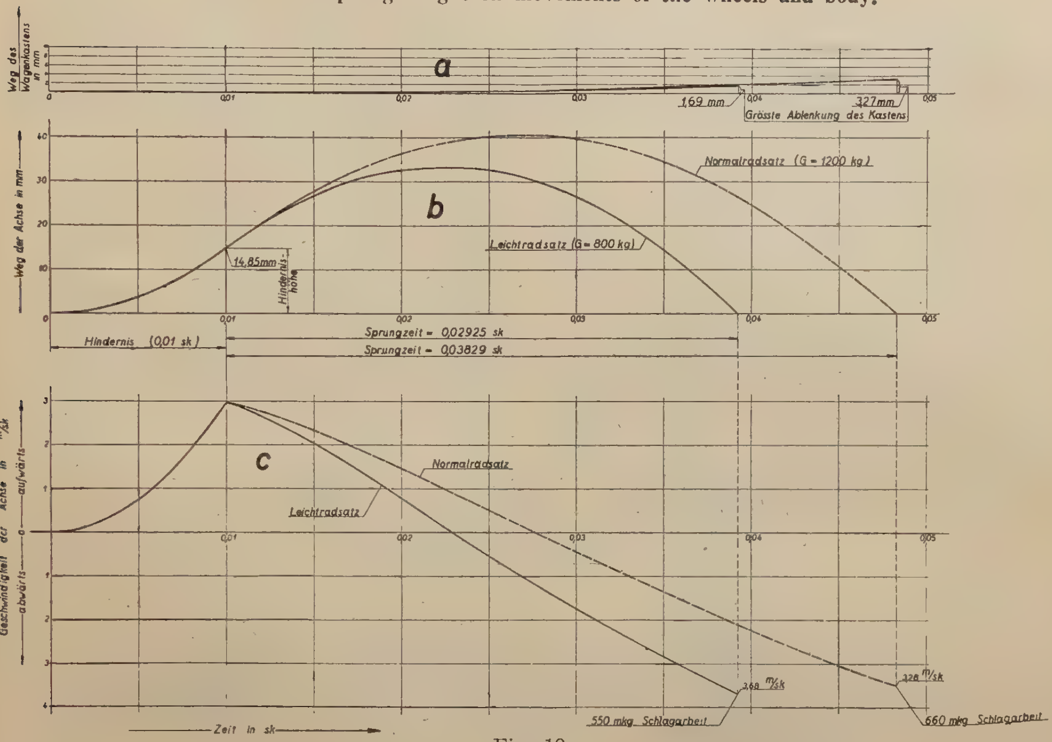


Fig. 19.

Explanation ~~of German~~ terms :

Weg des Wagenkastens in mm. = Trajectory of body in mm. — Grösste Ablenkung des Kastens = Maximum deviation of body. — Weg der Achse in mm. = Trajectory of axle in mm. — Hindernis = Obstacle. — Hindernishöhe = Height of obstacle. — Sprungzeit = Period of jump (from leaving obstacle to striking rails). — Normalradsatz = Standard wheel set. — Leichteradsatz = Light wheel set. — Geschwindigkeit der Achse in m/sk = Speed of axle in mm./sec. — Aufwärts = Upwards. — Abwärts = Downwards. — Zeit in sk = Time in seconds. — Schlagarbeit = Energy of impact.

and a sprung weight of 13 800 kgr. (30 400 lb.) are considered.

The wheels mount the obstacle and, after leaving it, pass along a trajectory shown by the full line in figure 19*b* for the light wheels, and by the dotted line for the heavy wheels. At the end of the trajectory the light wheels strike the rails, a blow corresponding to a stored energy-content of 550 Kg.-M. (3 980 foot-pounds), compared with 660 Kg.-M. (4 770 foot-pounds) in the case of the heavy wheels. What is of special interest, however, is the effect on the sprung weight. Up to the moment of leaving the obstacle, the wheel set exerts practically no influence on the sprung weight, but under the influence of the subsequent trajectory-motion of the wheels, the body moves upwards by an amount which is nearly twice as great in the case of the heavy wheels as in that of the light wheels. This demontrates the effect of the unsprung weight on the sprung weight, and shows the necessity for reducing the unsprung weight. Only in this way can the most effective reduction of vehicle weight be secured.

A new construction for a light wheel set is shown in figure 20. This con-

struction, patented by the Waggonfabrik Uerdingen, is about 30 % lighter than the standard type, and is based on the use of hollow axles. The use of hollow axles is not new in itself, but hitherto it has been impossible to employ hollow axles with thin walls because the usual hub constructions resulted in excessive surface pressure at the end of the boss. In the case of solid axles, the stress is increased simply by the transverse contraction resulting from this pressure; but, in the case of hollow axles, stress is also increased by the effect of the transverse contraction resulting from the tangential stress in the annular cross section of the axle. With an ordinary boss extraordinarily high stresses would thus be produced at the entrance, but this is avoided in the construction illustrated (fig. 20) by the use of a conical boss. The surface pressures and the resulting supplementary stresses are approximately proportional to the wall thickness of the boss and are therefore a minimum in the dangerous section, i. e. at the entrance to the boss. The use of thin-walled axles is thus made possible. A further step in this direction lies in the use of high-grade material for the wheel centre. The radial elasticity of the boss can thus be increased

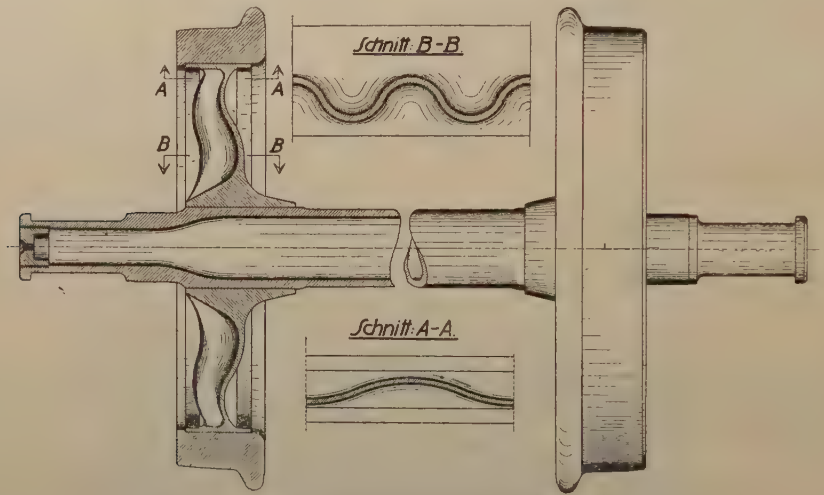


Fig. 20. — Uerdingen type light wheel set.

to about three times that of existing constructions so that, with the same machining tolerances, the range of forcing-on pressures can be reduced to about one-third of the existing ones. If, for example, this range has hitherto been about 40 tons, it can be reduced to about 13 tons in the construction now considered, thus further reducing the secondary stresses in the axle. The improvement in quality of the wheel centre involves also a greater radial elasticity of the outer part rim which is pressed against the tyre. This permits a considerable increase in the shrinkage allowance, giving greater security against loosening of the tyres as a result of heat developed by braking. In order, however, that this radial elasticity of the rim may actually be secured, the wheel disc must be corrugated radially as well as tangentially.

A further reduction in unsprung weight may be effected by inserting rub-

ber between the tyre and rim. A new construction of this type is shown in figure 21.

In this construction, a wheel centre pressed on to a hollow axle is separated, by a cupped or dished rubber ring, from a second wheel centre which carries the tyre. A tie rod through the centre of the axle holds the outer disc of each wheel in place, and subjects the rubber ring to both axial and radial tension; the flanges of each pair of wheel-centres being slightly inclined against each other in the axial direction, the rubber is subjected to a wedging action. This arrangement is intended for inside bearings. The main object in placing the rubber under initial compression is to render as harmless as possible the torsional stresses imposed on the rubber during running and braking. Obviously, the shape of the rubber must be such as to permit of its appropriate deformation, otherwise it cannot act elastically.

Figure 22 shows a rubber-sprung wheel arranged for outside bearings. A ring is bolted to the periphery of a wheel centre shrunk on to the axle, the wheel centre and its side-ring forming an open annular groove in which there is placed a ring of I-section, carrying the tyre. The I-ring is supported by an internal rubber ring *a* and the side rubber rings *b*, *b*, as shown in figure 22. The effect is the same as in the construction previously described and, here again, the rubber must be subjected to initial bracing and provided with sufficient room for deformation. If desired, the solid axle can obviously be replaced by a hollow axle.

As in both of the constructions just described, the unsprung weight is reduced to only that of the tyre or the wheel centre directly attached to it, the weight of the body can be reduced very considerably without sacrificing smooth running.

Figure 23 shows a tramcar of the same capacity as a standard 4-wheeled vehicle

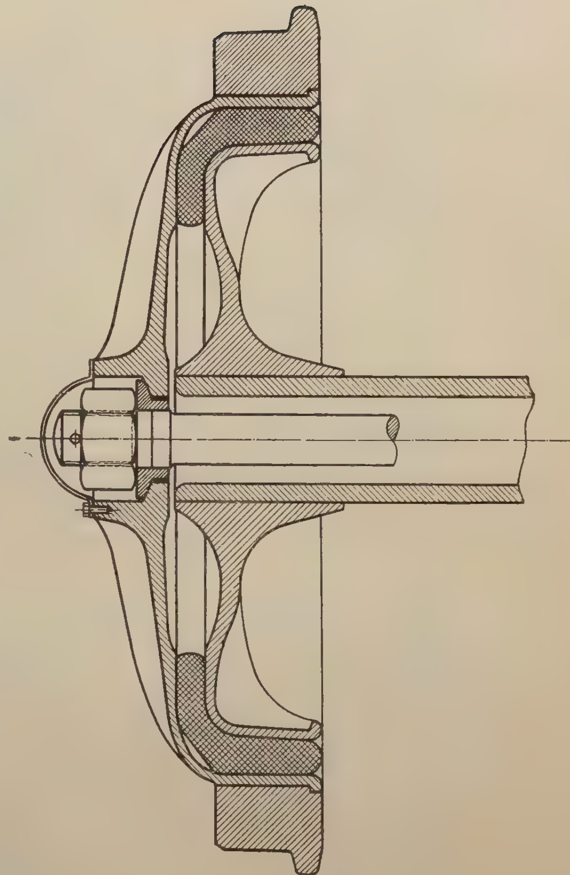


Fig. 21. — Uerdingen rubber-sprung wheel construction.

but, whereas the weight of the latter is at present about 13 tons, the car shown in figure 23, though 8-wheeled, weighs only 9 tons. Its riding qualities are considerably better than those of the four-wheeled car, partly owing to the relatively great distance between the bogie centres, compared with the wheelbase of the four-wheeled car, and partly owing to the rubber-sprung wheels. The latter permits also a specially simple bogie construction (fig. 24). As the axles are sprung, though only in a small measure the motor can be mounted rigidly

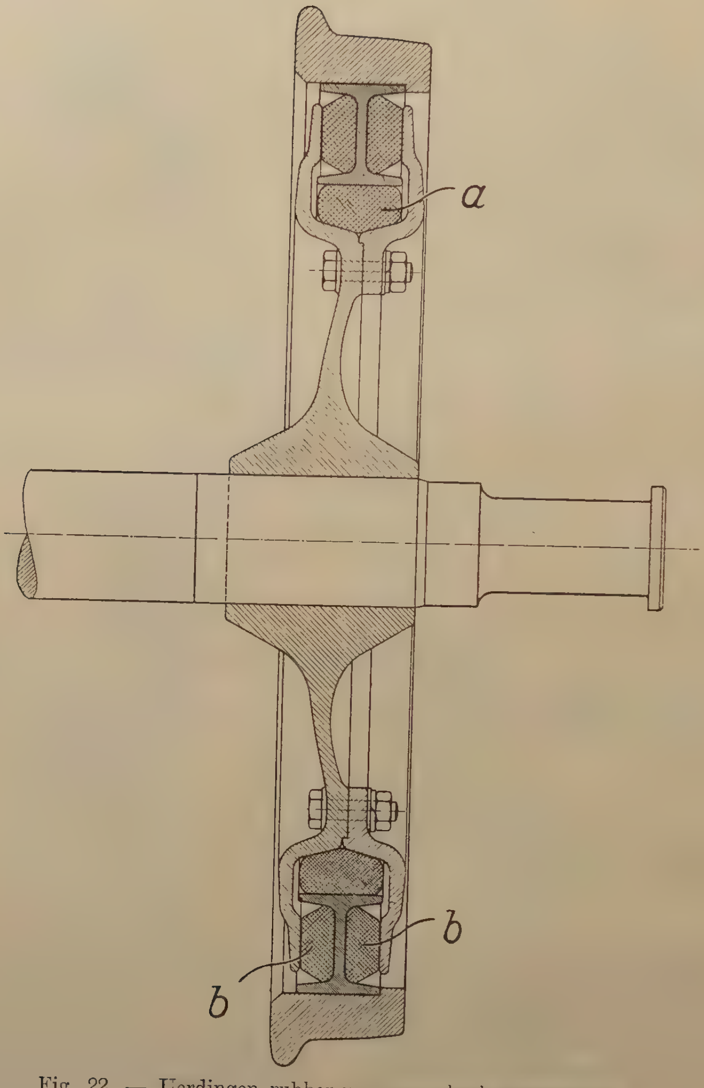


Fig. 22. — Uerdingen rubber-sprung wheel construction.

with respect to the axles. The motor and bogie frame may thus form one unit with fixed bearings for the axles. A single motor can then drive both the axles of the bogie through simple bevel gears, without the use of cardan joints. Also, long life may be expected from the bevel gears since they run under the same conditions as in stationary service. The body rests on spiral springs accommodated in spring seats cast on to the bogie frames.

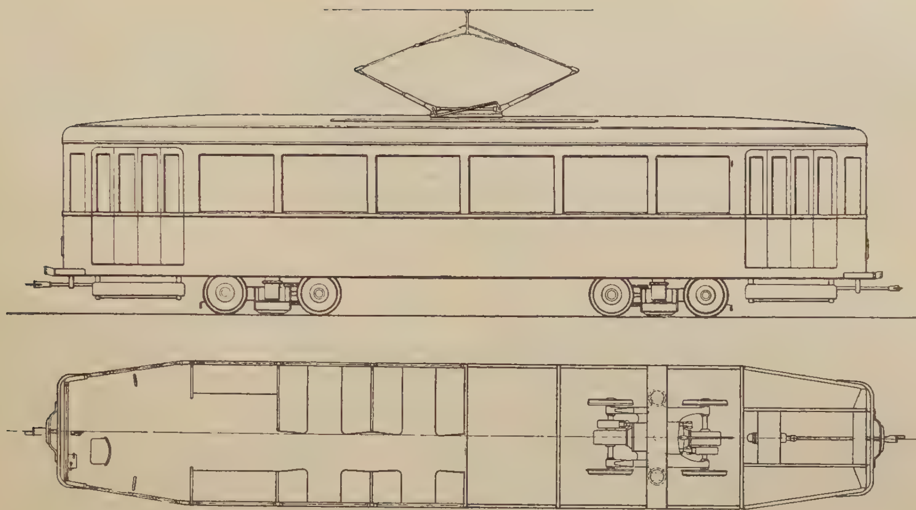


Fig. 23. — Eight-wheeled tramcar, Uerdingen design.

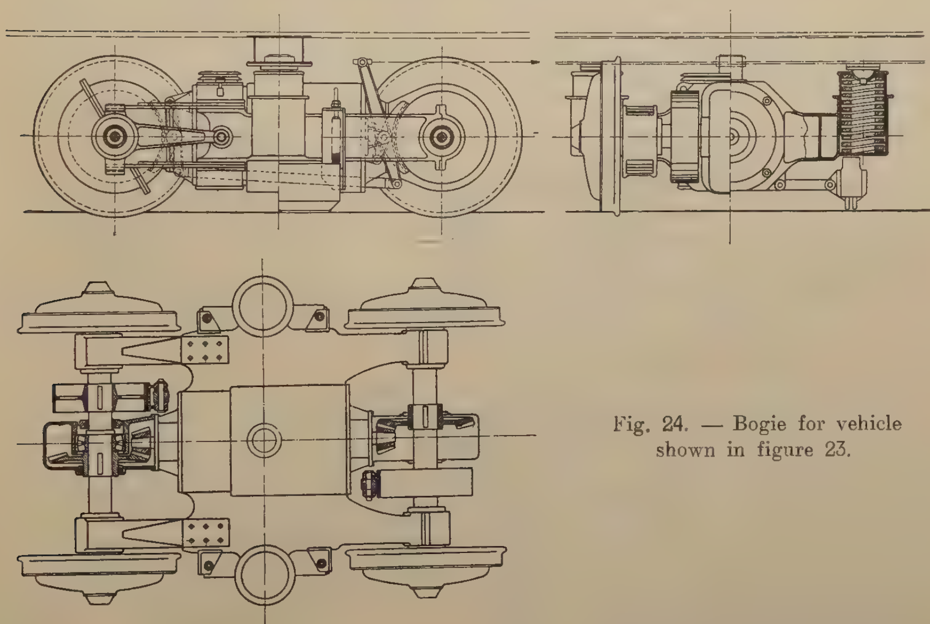


Fig. 24. — Bogie for vehicle shown in figure 23.

Figure 25 represents a four-wheeled vehicle with internal combustion motor drive, based on the same constructional principles. Here again, rubber-sprung axles are used, and the motor is mounted in a frame which carries the two axles rigidly. Cardan joints are again avoided, and a considerable saving in weight is effected.

In the articulated vehicle shown in

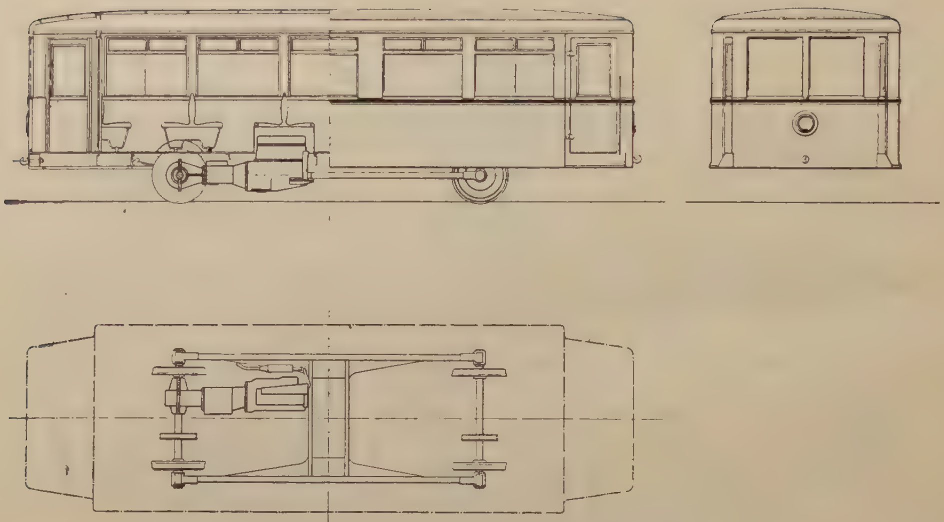


Fig. 25. — Four-wheeled rail omnibus with internal combustion motor, Uerdingen design.

figure 26, a four-wheeled bogie is provided at the centre, i. e. at the point of articulation, and guided driving axles are fitted at each end. The bogie construction is broadly the same as already described but without a motor, two mo-

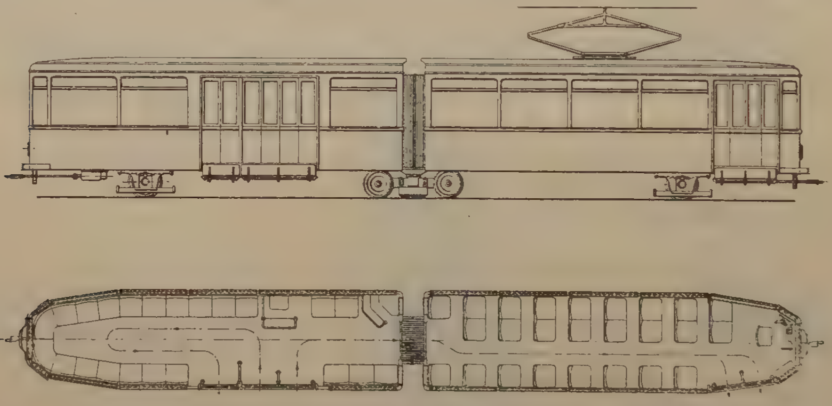


Fig. 26. — Articulated coach with 2 guided driving wheels at each end (« Bäseler » system).

tors being used on the end axles which carry about four-fifths of the adhesive weight. This vehicle accommodates about 110 persons and weighs about 13 tons. It thus represents about the limit at present attainable in the construction of light vehicles.

Discussion.

Herr Boden, Regierungsbaumeister. — I may add, to the information given by Herr Kreissig, some experiences of the Berlin Tramways. The light-alloy wheel set with hollow axle, described by the

author, effects about 30 % reduction in weight compared with standard wheel sets, but unfortunately this advantage, so very desirable to all street railway authorities, is purchased at the expense of trebled cost. Moreover, the difference in price is not fully compensated by the savings in track and vehicle maintenance.

If the hollow axle be omitted, but use be made of a light alloy wheel centre, the saving in weight amounts to 78 kgr. (172 lb.), or about 25 % per wheel set, and the price difference is only about 110 Rm. against the light alloy (1 1/2 times the price of ordinary construction). Allowing for the higher scrap value of the light alloy, the light alloy wheel set is only about 20 % dearer. A part of this extra cost is balanced by saving in electrical energy consumed. The Francfort and Berlin tramways have made preliminary tests with such wheel sets (of Elektron metal). Satisfactory results have been obtained and the trials will be extended as soon as general economic conditions improve.

Herr Kreissig refers also to the use of rubber in wheel sets. Tests made in Berlin have not been entirely satisfactory. In one case oil or grease from the axle box destroyed the rubber.

Special provision must be made for re-turning the tyres, in order that they may be kept circular.

If the rubber is to serve its purpose, it must be capable of expanding, but the space availalbe for this in small wheel centres is very restricted. For the wheel pressures concerned, the rubber is heavily stressed and therefore becomes brittle after a comparatively short time. If this is to be avoided, the rubber must be gripped from all sides, but it has then no springing action.

Tests have shown that such wheel sets give no smoother running than ordinary wheel sets with well graded helical or laminated springs arranged in series. It must be admitted that vehicles with rubber-sprung wheels run more quietly than ordinary wheels, especially disc wheels. Also, the unsprung weight is considerably reduced, but these advantages are obtained at the expense of trebled price.

Herr Kreissig also described a construction in which a single motor drives both axles of a bogie or a four-wheeled vehicle.

Experience with such arrangements has been obtained by several tramway authorities, and it has been found that the two wheel sets driven together cannot be kept of exactly equal diameter in service. This leads to expensive maintenance of the power transmission components. The difficulty can be overcome by the use of differential gears, but this construction has not yet succeeded, in spite of many trials.

In conclusion, although it does not bear directly on the subject of the present paper, it is interesting to note that the Berlin Metropolitan Railway has had two motor coaches and one trailer built of light alloy, the body frame and panelling (but not the main bearers) being made of « Lautal ». The saving in weight amounts to about 4.5 tons per motor coach or trailer, representing about 14 % for the whole train.

Dr. Kühnel. — The author has dealt with many problems which are of decisive importance in relation to the development of vehicle construction. As one engaged in the testing of materials, I may refer to the influence of corrosion and the effect of the boss on the fatigue strength of axle steel. During the year various publications will appear dealing with the effect of corrosion on fatigue strength and providing the designer with the desired basic information. Primarily, it is the « notch » formed by corrosion that endangers the fatigue strength and reduces it so seriously. I attach no special importance, in this connection, to the occurrence of so-

called « Edelrost » (fine rust) which I regard as a subsidiary phenomenon, not dangerous in itself but indicating that something dangerous to the axle is occurring. Tests are in progress in order to determine what influence the boss exerts on the material of the axle; whether the anticipated deterioration in fatigue strength is simply the consequence of pressure or whether it is due also to notch effect; and what is the extent of the deterioration. The results of the tests will be communicated to this Society in due course (1).

Herr KREISSIG (in reply). — I thank Dr. Kühnel for his interesting remarks, and particularly for his readiness to assist in solving the axle problem. I should be glad if he could make the results of his investigations available to us at an early date, in view of their importance in connection with the new designs.

In reply to Herr Boden, may I say that the prices for the new equipment are at present those for experimental constructions, and are therefore relatively high. The cost of patterns and dies has to be added to the inherently high cost of manufacture in such a case, resulting in a price which could be much reduced in repetition manufacture.

(1) This has since been done : « Achsbrüche an Eisenbahnfahrzeugen und ihre Ursachen » (Axle fractures on railway vehicles and their causes), *Glasers Annalen*, vol. 110, Nos. 4 and 5.

A considerable saving in weight can, of course, be effected by using light alloy wheel discs, but the latter are not applicable if there is a risk of the tyres being raised to a high temperature by braking. Naturally, use will be made of everything possible contributing to a reduction in the unsprung weight, provided that the production cost remains economical; as to this decision can only be reached on the basis of experience.

As regards rubber-sprung wheel sets, these cannot effect any considerable increase in the total spring deflections; their purpose is simply to destroy the troublesome high frequency oscillations at the place of their origin. This is feasible by observing the constructional principles explained, the object of which is to subject the rubber to only a permissible stress and to provide sufficient room for its expansion.

Concerning the driving of two sets of wheels by a single motor, it may be remarked that the power transmission components concerned are designed for the maximum adhesive torque so that, even with wheels of different diameters, the driving mechanism cannot be damaged. It must be left to experience to show to what extent the rubber insertions are a help or a hindrance in such a case. If necessary, it is clearly possible to install two motors in a single casing, each driving one wheel set. This would not alter the principle of the construction in any way.

[625. 234 (.73)]

Air conditioning of passenger cars established in two years.

(*Railway Age.*)

The never-ending search by man for increased comfort and greater luxury has been the prime factor in developing present-day civilization. Always the discomfort of being too hot or too cold, having too much or not enough « fresh air » has been with us, until in comparatively recent years the engineers began serious work on the problem of controlling inside atmospheric conditions. Unfavorable atmospheric conditions in factory buldings were found to be a serious handicap in securing production. The off season for theatres and department stores was during the hot summer months when patrons and shoppers stayed away, because such places were uncomfortable. Thus the impetus to the development of air-conditioning equipment was received when a serious effort was first made to fill in the seasonal valleys in the business-cycle chart.

The idea of improving the surrounding atmospheric conditions in which we live and work is not new. About 1900 a system for washing the air was installed in the British Parliament buildings, London. This system consisted primarily of blowing the air through a series of water sprays as it entered the buildings. It was soon discovered from this and other similar installations that the temperature of the water had considerable to do with the temperature of the rooms.

It was from the experience with air-washing systems that the relation of temperature and humidity to human comfort and the need to control these two factors were developed. This development did not progress to any considerable extent until after the World War when systems were developed and placed on the market for washing and cooling the air by using cold water. The pioneers in this development were Willis H. Carrier, chairman, Carrier Engineering Corporation, and at that time chief engineer of the Buffalo Forge Company; the Warren, Webster & Company, Camden, N. J.; B. F. Sturtevant Company, Boston, Mass., and the York Ice Machinery Corporation, York, Pa.

The first air-washing and cooling equipments were large and occupied considerable space. Installations were first made in factories, the products of which required cool inside temperatures for satisfactory manufacturing. Engineering research constantly improved the systems for washing and cooling air by developing apparatus which would control both temperature and humidity. Water for cooling was replaced by refrigerating units which considerably reduced the amount of space required for the equipment. Thus the « science » of air-conditioning was born.

The success of factory installations for air-conditioning led to its application in theatres, where it developed considerable prestige as an important factor in securing increased patronage during the hot summer months when heretofore theatre attendance dropped to low figures. From theatre installations, the demand for air-conditioning spread to department stores and office buildings. Then as smaller units were developed and placed on the market for small

Fig. 1. — The first air-conditioned car. — Baltimore & Ohio coach on which the first tests were conducted during the Summer of 1929.

stores, homes and individual offices, the idea of air-conditioning passenger cars began to take tangible form.

Baltimore and Ohio pioneers in air-conditioning passenger equipment.

Credit for pioneering in conditioning the air in railroad passenger cars belongs to the Baltimore & Ohio. In July, 1929, a Baltimore & Ohio day coach was equipped for complete summer air-conditioning. This installation was made in co-operation with the Carrier Engineering Corporation which assisted in the engineering tests and development work. The tests with this coach

were successful and the railroad decided to equip one of its colonial dining cars, the « Martha Washington », for air-conditioning. On 14 April, 1930, a test run was made with this car from Baltimore, Md., to Cumberland (1). Following these and subsequent tests, the car was placed in regular service. At the present time the road has over 100 passenger cars in service which are equipped for air-conditioning by the York Ice Machinery Corporation.

The Atchison, Topeka & Santa Fe was the next railroad to equip a passenger car for air-conditioning (2). This car was also a dining car, equipped by Carrier, in which installation a number of improvements were incorporated. It was placed in transcontinental service and has operated successfully across desert country since the summer of 1930. It was established on the initial test runs, that with the car loaded with passengers and with the kitchen stoves in operation, it was possible to maintain a temperature of 72° F. or less in the dining room with an outside temperature of 104°. The wide range of temperatures in the territory through which the Santa Fe operates places severe demands on the air-conditioning equipment. It is reported that this road now has 12 dining cars in service equipped for air-conditioning, ten of which have systems furnished by Safety Car Heating & Lighting Company.

(1) *Railway Age*, 9 August 1930, page 267.
(2) *Railway Age*, 23 August 1930, page 362.

Progress made since 1930.

The pioneer work during the summer of 1930 by the Baltimore & Ohio and the Fanta Fe led to further development work on the part of other railroads and of manufacturers of air-conditioning equipment. The year 1931 marked the purchase and trial of equipment by the Pennsylvania, the Missouri-Kansas-Texas, the Boston & Maine, and the Chicago

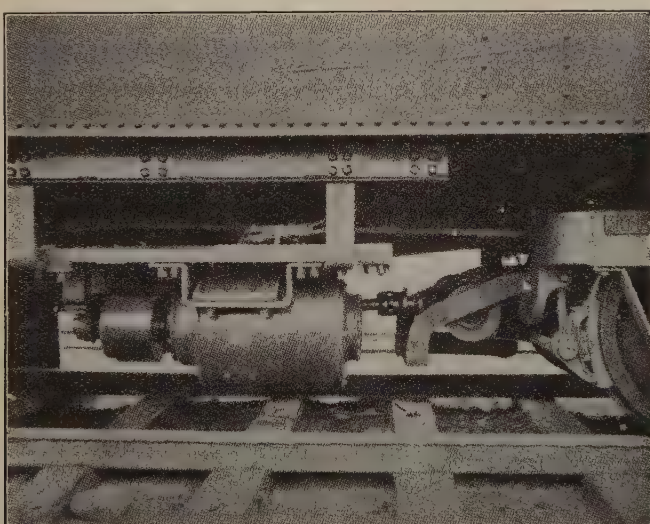


Fig. 2. — Axle generator which supplies power for York Ice Machinery Corporation's air-conditioning system, with compressor refrigeration.

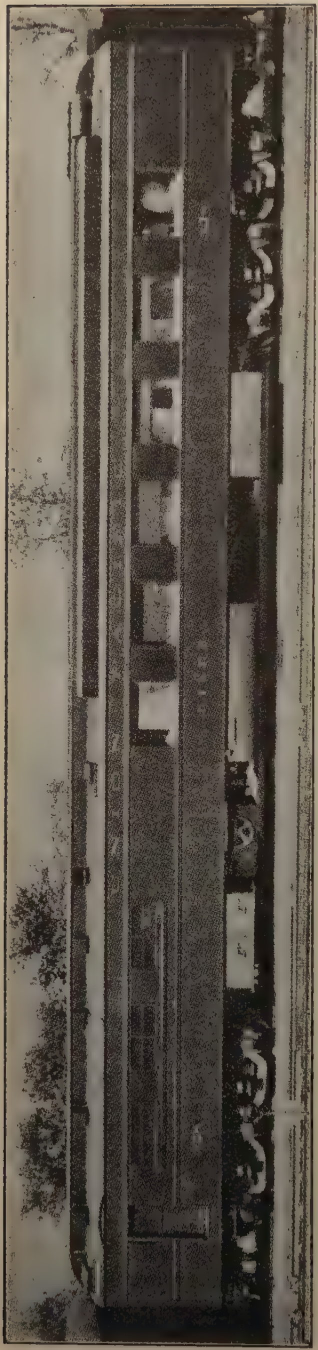


Fig. 3. — Union Pacific diner equipped for air-conditioning by the Pullman Car & Manufacturing Corporation.

& North Western. The York Ice Machinery Corporation completed the initial development of its air-conditioning equipment for passenger cars and equipped the « Columbian » trains of the Baltimore & Ohio (3). The Carrier Engineering Corporation, in conjunction with the Safety Car Heating & Lighting Company, New Haven, Conn., and the Vapor Car Heating Company, Inc., Chicago (4), developed a system of air-conditioning using water as a refrigerant. Steam from the train line supplies most of the power required to operate the system.

The Melcher Company, which has been absorbed by the Modine Manufacturing Company, Racine, Wis., developed a « unit system » of air-conditioning. This system was first tried out by the Chicago & North Western during the summer of 1930, and the tests were continued during the following year (5).

A system which uses ice for cooling was developed during 1931 by the R. B. Engineering Corporation, New York, and the Boston & Maine (6), the equipment being furnished by the B. F. Sturtevant Company, Boston, Mass. This development was sponsored by the Metropolitan Ice Company, Boston.

The Pullman Car & Manufacturing Corporation has developed a mechanical system using Freon as the refrigerant, which is installed on the « George Washington » train (7) on the Chesapeake & Ohio, and York also has further improved its system for the use of Freon as a refrigerant and has developed an improved system of power supply. The American Car & Foundry Company has developed its « Thermo-Gravity » system (8) which uses ice for a cooling

(3) *Railway Age*, 31 October 1931, page 675.
(4) *Railway Age*, 12 September 1931, p. 398.
(5) *Railway Age*, 26 September 1931, p. 469.
(6) *Railway Age*, 17 October 1931, page 588.
(7) *Railway Age*, 30 April 1932, page 718.
(8) *Railway Age*, 14 May 1932, page 825.

medium. The Westinghouse Electric & Manufacturing Company has equipped both sections of the Illinois Central « Daylight Special » with mechanical refrigerating air-conditioning units (9). The latest contribution to the field of air-conditioning passenger cars is that of the Rails Company, New York, which equipped two dining cars of the New Haven's « Yankee Clipper » with its Airtrol system using ice (10).

Eight manufacturers offer choice of eleven equipments.

At the present time eight manufacturers of air-conditioning equipment have developed units for rairoad service. Three of these companies have developed both ice cooling and compressor refrigerating units for application to passenger cars, which give the railroads a choice of eleven different equipments.

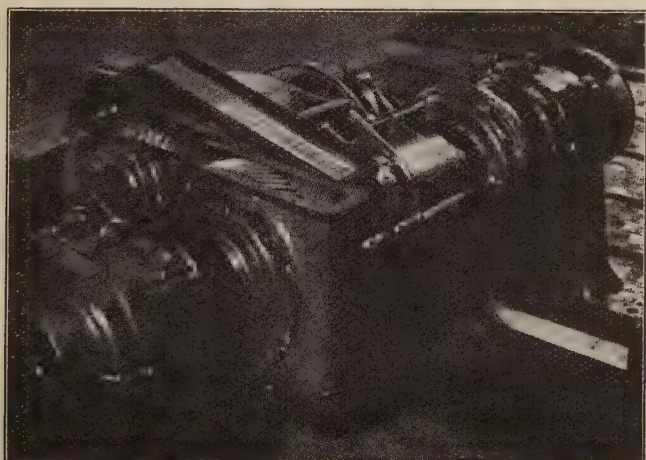


Fig. 4. — Axle generator used in the air-conditioning system of the Westinghouse Electric & Manufacturing Company. — The cover of the gear case is removed.

It is reported that a number of other manufacturers have developments under way or are seriously considering the railroad market for their air-conditioning equipment.

Hand-in-hand with the recent developments in air-conditioning equipment, several improved systems of passenger-car ventilation and precooling have been tried and found successful. One is the precooling units which a number of railroads are now using to precool cars, especially sleeping cars, prior to departure from terminals. Another is the Airgard window ventilator, a device manufactured by the American Air Filter Company, Louisville, Ky (11). This device accomplishes one of the important functions of air-conditioning units in that it filters and cleans the air as it enters the car, replacing the present suction system with pressure ventilation.

The need for providing air in passenger cars which is free from dust,

(9) *Railway Age*, 30 July 1932, page 140.

(10) *Railway Age*, 10 September 1932, p. 367.

(11) *Railway Age*, 23 April 1932, page 691.

dirt and cinders has long been recognized by railroad men. It has been found from experience with the various types of air-conditioning units, and also with the Airgard ventilator, that the slight pressure which is built up inside the car prevents the infiltration of dust and smoke around windows and doors.

This increase in air pressure is due to the action of the fans or blowers which draw the air through the cooling or cleaning units and circulate it through the car. As an assistance in attracting business and developing patronage, this feature which air-conditioning provides is of more importance in railroad operation than perhaps in any other field to which air-conditioning has been adapted. Complaints because of dirt and cinders have always been with the railroads since the days of the « Tom Thumb » and stage-coach cars.

Power supply.

The equipment thus far developed for conditioning the air in passenger cars falls into three classifications, depending on the source of refrigeration; namely, systems employing ice, the ejector-evaporator system and the compressor systems. The first two systems are alike in that they both employ water as a refrigerant or medium for transferring and dissipating the heat from the air passing through the air-conditioning units. The compressor system, however, requires a special refrigerant of low vapor tension, which is condensed by compression and, in all recently developed systems, expands directly through the air-cooling coils.

The most significant differences of the three classes, however, are in the character and amount of the power supply which they require on each car. All of the systems employ electric motors for driving blowers and in most cases for both blowers and pumps. It is not possible to compare one system with another operating under different circumstances, but a resumé of data concerning connected load and power or ice

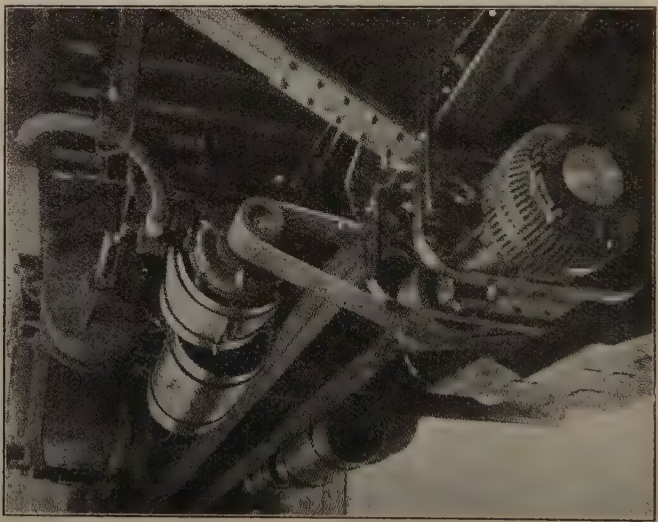


Fig. 5. — Underside view showing the electric speed control and V-belt drive from the stand-by motor of the air-conditioning system developed by the Pullman Car & Manufacturing Corporation.

supply is offered in the following to indicate the values required.

The Boston & Maine ice-cooled car designed by the R. B. Engineering Corporation and equipped by the B. F. Sturtevant Company, employs one 3/4-H. P. pump motor and two 1/2-H. P. blower motors. Experience has shown, however, that these motors are of greater size than is necessary. The power supply system, which is also used for lighting, consists of a 5-kw. generator and a 450-amp.-hr. storage battery. On a test run, during which the average outside wet-bulb temperature was 70° F. and the average dry-bulb temperature was 81, the ice consumption was 290 lb. an hour. On another run when the temperatures were 75 and 86 respectively, the ice consumption was 418 lb. an hour.

On the two New Haven diners equipped with the Airtrol system the dining room with a content of 4 500 cubic feet is cooled by a system employing one

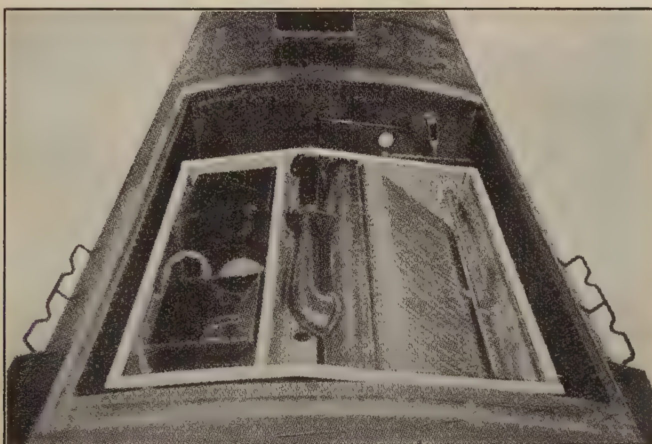


Fig. 6. — Safety-Carrier-Vapor Unit installed in a car. — The roof cover is removed to show the cooling and heating coils and air-intake duct.

1/4-H. P. pump motor and one 1/4-H. P. blower motor. For cars on which a larger space is air conditioned, two pump and two blower motors would be used. The two diners now in service have ice tanks with 1 500 lb. capacity which is sufficient for the run from New York to Boston, Mass.

The Thermo-Gravity ice system of the American Car & Foundry Company installed on Rock Island diners employs a 1/4-H. P. pump motor, a 1/6-H. P. pump motor and a 1/3-H. P. blower motor. These cars run long distances through territories where the temperature at times reaches 105° and arrangements are made for icing the cars en route.

The Safety-Carrier-Vapor system, using water as a refrigerant, obtains power for cooling the water from the train steam line. The steam operates an ejector which creates a vacuum in which the desired cooling of the water is effected by evaporation. When the system is operating at its capacity of five tons, it requires 170 lb. of steam per car per hour at the nozzle, or 205 lb. at the locomotive, allowing for 35 lb. loss per car in the train line. In addition to this there is an electrical load of 2.4 kw. for driving pump and fan motors. For

heating in the winter, the maximum steam requirement is about 260 lb. of steam per car per hour.

When refrigeration for air-conditioning is produced by a compressor which takes power from the car axle, it is difficult, if not impossible, to measure the additional amount of power taken from the locomotive. It is estimated that from 400 to 600 lb. of steam per car per hour at the locomotive is required to produce five tons refrigerating effect and to operate the necessary auxiliary equipment on each car. Several means of obtaining this power are in use. The limit of driving capacity of a single flat belt is about 5 kw. and other methods of drive therefore become necessary.

The first car placed in service on the Baltimore & Ohio was equipped with one 10-kw. and one 5-kw. generators, each of which was gear-driven from a car axle by a Diehl drive. Cold water was used for storage or refrigerating capacity.

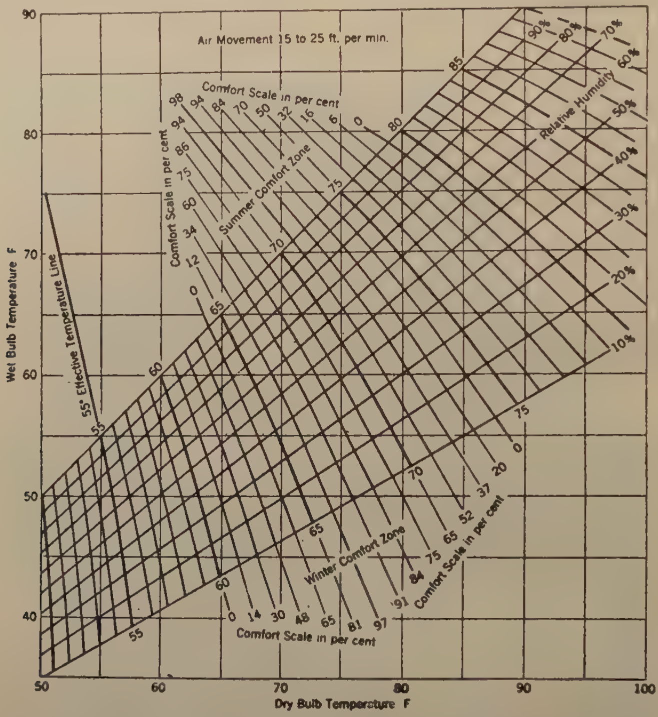


Fig. 7. — Chart showing the seasonal variation in the comfort zone. — Reproduced from the Engineer's Guide of the American Society of Heating and Ventilating Engineers.

The next system installed on the Santa Fe employs two safety 7 1/2-kw. generators with Foote direct drives from the inside car axles. Three 750-amp.-hr. Exide Ironclad batteries, with a total capacity of 2 250 amp.-hr. are connected in parallel across the line to provide reserve power for the cooling and lighting load at stations and at speeds below 15 miles an hour. A 7 1/2-H. P. motor drives the compressor, and smaller motors, also receiving their power from the battery and generators, are used to drive pumps and blowers.

When the Baltimore & Ohio equipped a number of cars in 1931, a gasoline engine was used on each car to drive the compressor and a pump. The use of the engines was discontinued at the end of the first season and power is now again taken from the car axle. Two flat belts connect one axle with bevel gears in a gear box suspended from the truck frame. A splined shaft, parallel with the car axis connects the driven gear with a multiple V pulley. The 7 1/2-kw. Fairbanks-Morse, third-brush generator is driven from this pulley by Dayton multiple V belts. The 7 1/2-kw. generator is assisted by the regular 4-kw. car-lighting generator with the usual single flat-belt drive. Power while standing or running at low speeds is supplied by a 1 000-amp.-hr. Exide Iron-clad battery developed especially for air-conditioning. As with the Santa Fe installation the compressor and auxiliary apparatus are motor-driven.

An electric system which requires small power consumption has been installed on the Chicago & North Western by the Modine Manufacturing Company. It is called a unit system, and as applied employs four motor-driven refrigerating units, two under each side of the car. The combined capacity of all motors used is 2 1/2-H. P. and power is furnished by a 5-kw., 32-volt generator and two 450-amp.-hr. batteries installed independently of the lighting system.

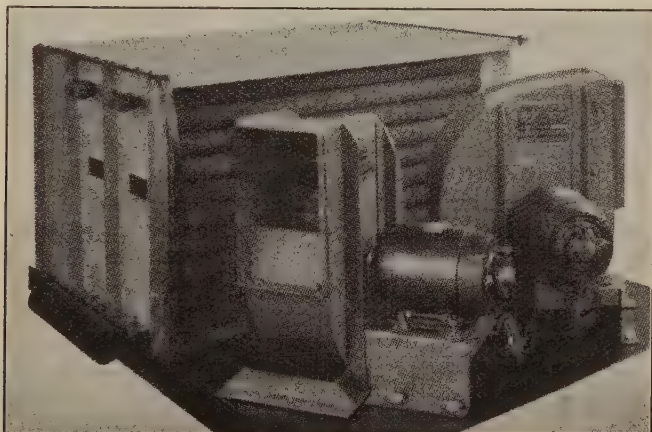


Fig. 8. — Westinghouse air-conditioning unit and direct motor-driven fans which are installed under the car roof.

A mechanical drive with an electric speed control instead of a generator and motor for driving the air compressor is used on the Chesapeake & Ohio cars equipped by the Pullman Car & Manufacturing Corporation. The device consists of an armature, gear-driven from the car axle, and a rotating field connected to the compressor. By varying the strength of the magnetizing current in the field, slip can be caused between the armature and the field and the speed of the compressor held practically constant, while the speed of the car and the armature varies. The car is also equipped with standard car-lighting battery and generator which supply power for the auxiliary apparatus as well as the lights. When the car is standing in the terminal the compressor can be operated from a three-phase 220- or 440-volt outlet. The motor for this purpose runs idle from the compressor shaft when the car is on the road; multi-

ple V belts connect the motor and compressor shafts. This is done to avoid the use of the heavy cables which are required for a 32-volt system.

The principal feature of the Westinghouse all-electric drive, applied to ten cars on the Illinois Central, is a 15-kw. high-speed generator, connected to the car axle by a nose suspended drive similar to that used for street-car and multiple-unit traction motors. The generator has its own exciter and in conjunction with a 1 000-amp.-hr. battery, supplies all of the car's requirements for air-conditioning and light. An a.c.—d.c. motor is used to drive the compressor. This motor operates from the battery and generator when the car is running or standing for short periods, and when the car is standing in the terminal the motor can be operated from an a.c. power supply during which time the d.c. winding can be used to charge the battery.

V belts have demonstrated their ability to haul greater axle-driven loads than is possible with a single flat belt and have been used successfully to drive a generator on an air-conditioned car.

A friction drive for air-conditioned cars was recently developed by the Dallas Machine & Locomotive Company, which can be used for driving one or two generators. It is now driving a 3-kw. machine on the Spokane, Portland & Seattle and is claimed to be capable of carrying loads ample for air-conditioning purposes.

Some of the drives now in service have introduced new maintenance problems and in some cases a considerable amount of yard charging of batteries has been necessary. In spite of this condition, the railroads with the equipment at hand have been able to supply highly satisfactory air-conditioned service.

The first cars equipped for air-conditioning used mechanical refrigeration. The refrigerant used was ammonia. Although this liquid has been used for years and is still used as the refrigerant in ice-making and other refrigerating processes, nevertheless its use in passenger cars was highly undesirable for obvious reasons. There were other refrigerants on the market or in the process of development which did nos possess the objectionable features of ammonia, but still did not meet railroad requirements with respect to safety.

Undoubtedly the rapid progress in the air-conditioning of theatres and other buildings where people congregate hastened the development of a refrigerant which would comply with local regulations and safety codes. Freon, a refrigerant produced by the Kinectic Chemical Corporation, Wilmington, Del., has already become an important factor in adapting compressor refrigeration to railway requirements.

This refrigerant boils at -21.7° F. and is odorless, non-irritating, non-toxic, non-flammable, and non-explosive. It is not corrosive and makes a stable refrigerant. It can be used in a small compressor and operates at low, but positive pressures. No hazard is involved in case of leaks in the system. For this reason it can be expanded directly through the air-cooling coils, thus eliminating the intermediate brine circuit with its cooling tank and pump. The latest compressor systems are thus much lighter than those in earlier installations and their power load has been somewhat reduced.

Air-conditioning, defined in its broadest sense, is the practice of simultaneously controlling two or more of the physical or chemical properties of air (12). However, in the development

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(12) The *Engineers' Guide*, 1932, published by the American Society of Heating and Ventilating Engineers, contains three chapters on the subject of air-conditioning. Much of the information contained in the following paragraphs is taken from this book.

of air-conditioning the terms have been more generally associated with the control of temperatures and humidity which are the two most important physical properties of air bearing on the comfort and health of man. In problems involving human comfort it is necessary to maintain certain limiting or desirable effective temperatures which depend on the experimentally determined relationship of wet- and dry-bulb temperatures and air motion.

From the standpoint of comfort and health, air-conditioning may be regarded as the art of maintaining the atmosphere of occupied spaces at a condition best suited to the physiological requirements of the human body. These requirements consist of maintaining simultaneously the proper temperature, humidity and air movement and a reasonable air purity with regard to dust, bacteria and odors.

Fig. 9. — Air duct laid along the carline of the lower deck of a car being equipped with a Thermo-Gravity system.

The American Society of Heating and Ventilating Engineers has sponsored considerable research relative to comfort and health especially from the standpoint of air-conditioning. The psychrometric chart shown is plotted from observations made in the research laboratory of the society.

The winter comfort zone as determined by the A. S. H. V. E. laboratory ranges from 63° to 71° F. The summer comfort zone ranges from 67° to 75° F. These effective temperatures average about 4° higher than those found in winter when heavier clothing is worn. Young men, as a general rule, prefer conditions in the cool region of the comfort zone shown on the chart, while women and older people prefer the warm region of the comfort zone.

At the present time there are approximately 250 passenger cars equipped for air-conditioning in service or being equipped in the United States. The Baltimore & Ohio has the largest number of cars thus equipped. The Chesapeake & Ohio ; Chicago & Eastern Illinois ; St. Louis-San Francisco ; Illinois Central ; Wabash ; Chicago, Rock Island & Pacific ; Pennsylvania ; Missouri-Kansas-Texas ; Chicago & North Western ; Chicago, Milwaukee, St. Paul & Pacific ; Santa Fe ; Union Pacific ; Alton, and Southern Pacific have all the cars of one or more trains, or the dining cars

only, equipped. The New York Central is air-conditioning its « Twentieth Century Limited » and a number of other trains.

Air-conditioning introduces a complete new era in passenger-car ventilation and heating which promises to effect almost as much improvement in the comfort and desirability of railroad travel at all seasons as does the air-cooling function during the summer months. Considering the fact that for many years ventilation of railway equipment has depended upon the suction ejector principle, which produced a slight vacuum within the car and depended for effectiveness on the infiltration of highly dust-laden air around windows and doors, dirt in disagreeable quantities has always been the price of air changes in the interior. The air-conditioning systems which so far have been installed have reversed this action and control the ventilation at the intake. This permits filtering and, by slightly raising the pressure of the interior, allows the air to filter outward around the windows and doors and through any other openings which may be available.

But unless the air-conditioning units are arranged to operate during the heating season, the pressure-ventilation function will cease with the end of the cooling season and the dirty conditions of suction ventilation will prevail for most of the year. Most of the systems now on the market provide wholly or in part for heating the cars during cold weather by radiation in the air-conditioning units. Some of these units are already provided with humidifiers for use during the heating season to overcome the characteristic aridity of interior atmospheres during cold weather. These additional functions, which provide for complete, year-round air-conditioning service, do not add greatly to the weight or space required and, under the present state of the art, can be provided with complete automatic control if desired.

Within two years after the pioneer installation of equipment to effect summer cooling of the atmosphere within passenger cars, air-conditioning has been so completely adapted to passenger-car requirements that complete control of their interior atmospheres has become entirely practicable. Considering the rate at which active interest has spread among the railroads during this period of development in technique, a prediction may be ventured that long-distance railroad travel will soon stand out in the mind of a fastidious public as one of the most comfortable experiences offered by our modern civilization.

[625. 143 5]

Modern rail joints.

(*The Railway Engineer.*)

The last few years have witnessed renewed efforts to improve rail joints; possibly these have been inspired by the necessity of reducing the cost of joint maintenance which under increasing axle loads has shown signs of becoming even greater than before. New designs of joints have been experimented with in various parts of the world, and it is proposed here to describe those which, according to reports available, appear to be as improvement upon previous forms.

The general trend of modern design is interesting in several respects; the suspended point, almost universally used until a few years ago, is giving way on the Continent to supported or semi-supported types, thus reverting to a practice which found favour for a time in this country but was subsequently discarded. There now appears also a tendency to make the fishplates as short as possible — in fact, very short plates employing only two bolts are gaining popularity, a complete reversal of the one time policy of endeavouring to strengthen the joint by using long — some of them six-bolt — fishplates. This change is, perhaps, due to a widening opinion that the primary purpose of a fishplate is to resist shear rather than bending. While it may be that this may lead to improved design, theoretically the ideal joint is obviously one which maintains the continuity of the rail when it is considered as a beam.

British standard rail joints.

The British standard joint (fig. 1) which is used on track in this country is of the normal suspended type, and represents the continuation of a policy of many years' standing. Beyond being simple and cheap, it has no special

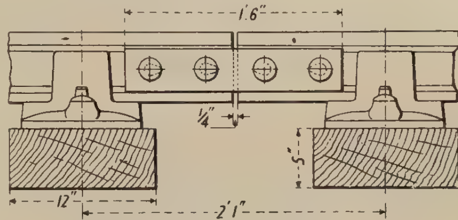

Fig. 1. — British standard joint.

feature; it is considerably weaker than the solid rail in resistance to both bending and shear. The smooth running realised on British railways is undoubtedly due to the careful fettling and attention given to the joints, offsetting weakness in design. In an attempt to neutralise the lack of strength in the joint itself the sleeper spacing at and adjacent to the joint is reduced somewhat, while some railways use timbers 12 inches wide with wide-base chairs at the joints in order to provide additional support.

Quite recently certain railways in this country have adopted a modification of this type of joint by using standard B. S. S. fishplates only 9 inches long with two bolts, the purpose being to get the joint sleepers close together and thus, by reducing the length of the cantilevered rail ends, strengthening the joint. At the same time, of course, this is achieved at appreciably reduced cost.

A patent plate, called the Joyce « Anti-impact », is now obtainable. This fish-

plate, which is drop-stamped, has been designed with a view to overcoming the structural weakness of the B. S. joint; it is marketed by Henry Williams Limited, Darlington. It will be seen from the drawing, figure 2, that the centre portion has been thickened to provide increased strength. Consistent with modern design its virtual length is much less than that of the normal B. S. plate, the length of contact with the fishing surfaces of the rails being only 7 inches at the top and 9 inches on the lower surfaces; the remaining 4 1/2 inches at each end of the plate stand entirely clear of the rail. The outer bolts appear to be

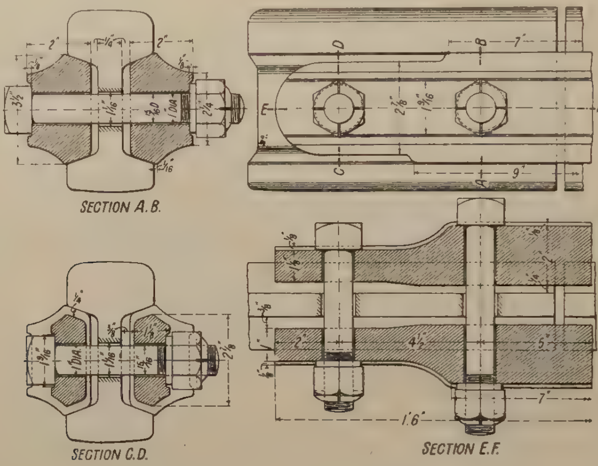

Fig. 2. — Joyce fishplate.

acting chiefly in the capacity of emergency fastenings in case of failure of the inner bolts, which take most of the strain.

The head-free joint.

In North America, where axle loads are particularly heavy, the battering of rail ends in spite of the introduction of rails weighing 130 lb. per yard, had threatened to become a serious matter. It is claimed that this trouble has been eased very much by the introduction of the head-free joint. This joint is described in detail in an article which appeared in the 11 March issue of our associated contemporary, *The Railway Gazette* (1). The particular feature of this joint, shown in figure 3, lies in the fact that the usual bearing between the upper sur-

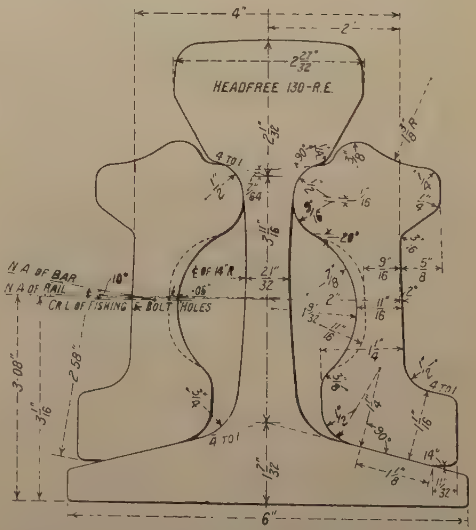

Fig. 3. — Head-free joint with head-free rail.

face of the plates and the fishing surfaces of the rail-head has been with the fillet between the head and web of the

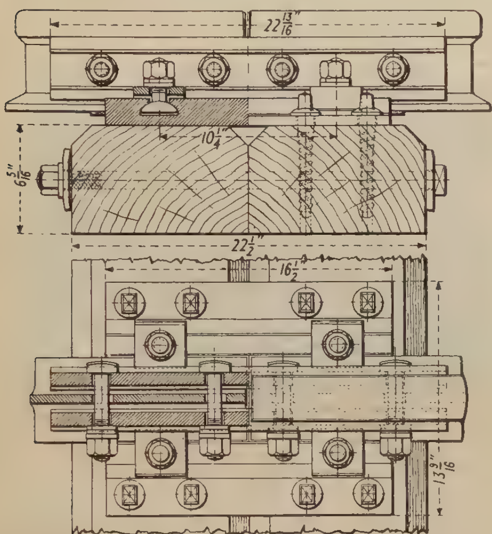

Fig. 4. — German bolted joint sleepers.

rail. This very satisfactory joint is now standard on over thirty North American railways.

Standard joints on Continental railways.

In France, Germany, Italy and other Continental railways, the joints adopted as standard show a considerable degree

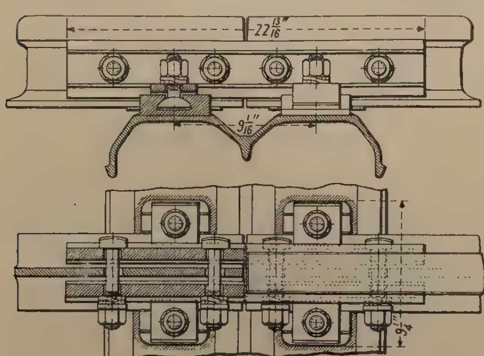

Fig. 5. — German twin steel sleeper.

of similarity. The fishplates bear against the fishing surfaces of the rails in accordance with normal practice, but the joint sleepers are placed much closer together than has hitherto been the practice in this country, in fact on certain railways the two joint sleepers are actually bolted together (fig. 4), thus forming virtually a single sleeper 22 1/2 inches wide by 6 5/16 inches deep. The ends of the rails are carried on a sole plate 16 1/2 inches long, the joint thus being to all intents and purposes of the supported variety. On steel-sleepered track a kind of twin sleeper approximately 17 1/2 inches wide is used, as shown in figure 5.

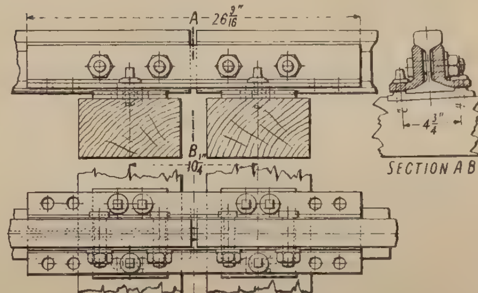

Fig. 6. — French standard joint.

The French standard joint is illustrated in figure 6. It differs from the German design in that the two 8 1/4 inch × 4 3/4-inch joint sleepers are spaced at 10 1/4-inch centres, and independent sole plates 6 inches wide are used; the space between the two sole plates is therefore about 4 1/4 inches and the joint may be said to fall within the semi-supported category.

On the Nord Railway, France, a special joint has been standardised, illustrated in figure 7. The outer fishplate is a channel section into which fits an oak key held by means of the fishbolts to the vertical arm of a steel saddle-bridge which supports the foot of the rails under the joint between the joint sleepers. These sleepers are placed 16 1/2

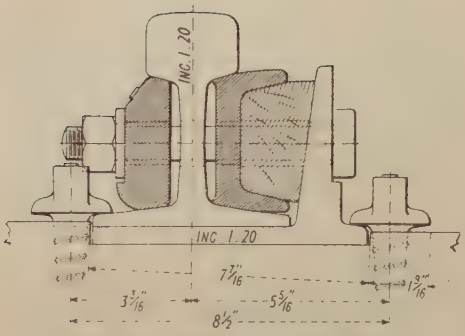

Fig. 7. — Nord standard joint.

inches centre to centre, and the fishplates are 25 inches long.

The chevron fishplate.

On the Midi Railway, France, a short type of fishplate has been adopted as standard. This plate is the outcome of extensive experimental research by Messrs. Coullié and Cadis, of the Midi Railway; it is known as the « chevron » fishplate, owing to the resemblance between the shape of its elevation and that of a soldier's chevron. About 8 3/4 inches long and with two bolt holes at 5.9 inch centres, this plate is shown

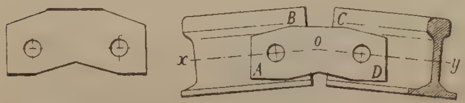

Fig. 8*a*. Fig. 8*b*.

Chevron fishplate.

diagrammatically in fig. 8 (*a*), the thick lines indicating the surfaces of contact with the rails. When the fishbolts are tightened the joint tends to take up the form shown in fig. 8 (*b*). In pratice it is found that the unloaded rail ends stand proud to the extent of 1/32 to 1/16 inch; as this condition is brought about by the elastic deformation of the components, firm and permanent contact at the surfaces of A, B, C and D is ensured. When a wheel comes on to the joint the angle *xoy* increases slightly and immediately resumés its former state as the laod is removed. A chevron joint is shown in figure 8 (*c*).

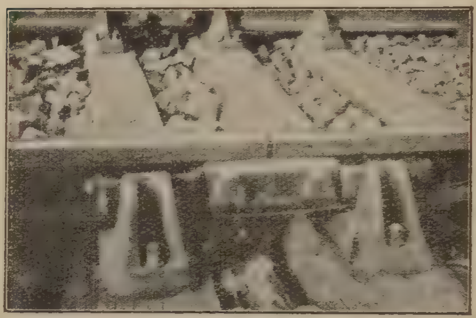

Fig. 8*c*. — Chevron joint.

Practical tests confirm that when the joint is loaded by a wheel the ends of both rails are depressed simultaneously and to an equal extent, a condition which does not obtain with the ordinary type of fishplate. Tests have been made to ascertain the relative smoothness of riding of joints equipped with standard and chevron fishplates respectively. A glance at the records reproduced in figure 9 will show that, whereas a definite vibration is found at every joint equipped with standard plates, it is difficult to detect any outstanding shock at joints fitted with chevron plates. It is possible that this desirable result is in some measure due to the closer spacing of the joint sleepers and is rendered possible by the shortness of these fishplates.

The chevron plate is proving economical in many ways; its first cost is small, as two plates can be stamped out of one old standard plate, and only two fishbolts are required instead of four. To avoid any risk of the fishbolt nuts becoming loose a simple locking washer is used (fig. 10); this can be easily opened when it is desired to remove the nut by

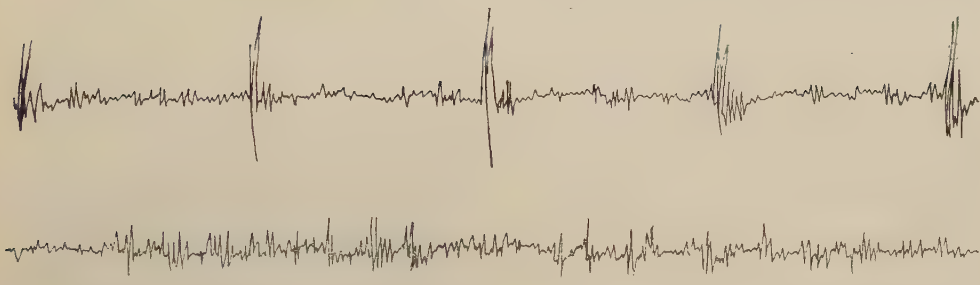

Fig. 9. — Records indicating benefit of chevron fishplates.

using a coin or a special key. It is claimed, as a result of experience on the Midi, that rail creep has been reduced; another important economic advantage has been realised, as, owing to the assur-

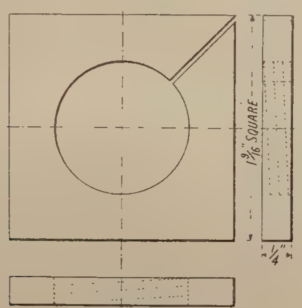

Fig. 10. — Locking washer for fisbolt nuts.

ed continuous contact between rail and plates (the contact surfaces are always found to be bright when the fishplates are removed), it has been found possible to dispense with the usual track bonding on electrified and track circuited lines.

The reconditioning of joints.

As the best of joints wear out in the course of time, it may be profitable to consider steps which may be taken to recondition joints which have become too worn for service. With the ordinary type of fishplate, wear takes place at the contact surfaces of both rails and plates and, although this wear can be taken up by tightening the fishbolt, the condition eventually arises when the fishplates come in contact with the web of the rail and they can be tightened no more. When this state is reached the supporting value of the plates is lost and battering of the rail ends soon follows.

The crude way of getting over this difficulty is to introduce thin packing strips between the bearing surfaces of the fishplates and rails, but unless these packings are used carefully distortion of the rail ends is likely to occur, rendering the rails unfit for high-speed tracks.

« Repair » fishplates.

On many lines in this country the difficulty has been overcome by fitting « repair » plates. These are new fishplates identical with the original plates except that they are 1/8 inch or so greater in depth in order to compensate for the wear on the fishing surfaces of rails. These fishplates, being usually of uniform depth throughout their length, are not entirely satisfactory, because the wear on the fishing surfaces of the rails is not uniform, being greater opposite the middle of the plates than it is opposite the ends; the result is that in order to obtain proper contact throughout their length the plates become drawn in more at the centre than at the ends. As repair plates are equal in price to the original plates this method of reconditioning joints is somewhat costly. There are, however, alternatives.

Joint shims.

Of these alternatives, one is a reversion in principle to the use of packings mentioned above, and is much used in North America. The packings in this case are of tempered steel and taper from the centre towards the extremities, thus overcoming the uneven wear difficulty met with when repair plates are used. These fittings, kown as « shims », are made in lengths from 9 inches upwards to the full length of the fishplates, and in various thicknesses at the centre between 1/16 inch and 5/32 inch. One of the great advantages of these shims is that, being quite light and made in a variety of sizes, a ganger can easily carry a selection with him on his round of inspection, and by simply slackening the fishbolts insert a pair of shims of a size suitable to the degree of wear which may have taken place at any particular joint. A sketch of these shims appears in figure 11, from which it will be noticed that there are vertical lugs at the centre; these butt against the centre fishbolts and prevent the shim creeping longitudinally, and further, being angular, there is no likelihood of the shim working out sideways. A joint with shims in position is shown in figure 12.

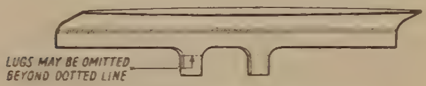

Fig. 11. — American joint shim.

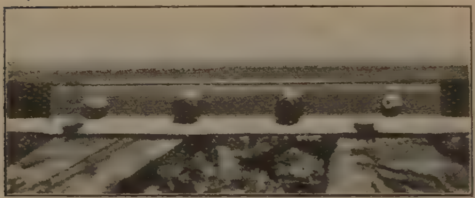

Fig. 12. — Joint with shims.

For use on electrified lines not using a fourth rail for the return traction circuit, where the running rails are bonded together with « protected » bonds (*i. e.*, bonds behind the fishplates), these lugs may be omitted. Experience has shown that without lugs creeping of the shims is inappreciable. These shims are marketed by Wonham Inc., of 68/72, Windsor House, Victoria Street, S. W. 1, and New York.

Reconditioned fishplates.

A further method of dealing with worn joints is to recondition the fishplates. The worn plates are heated and placed in a press. By means of a suitable die the depth of the plate is increased by the displacement of metal in the web of the plate. This displacement is brought about by the die, which makes a groove in the back of the plate just clear of the bolt-holes; the die is so designed as to cause greater displacement at the middle of the plate than at the ends, thus producing a predetermined camber on the top surface of the plate. As the result, the plate is thus similar in vertical section to a worn plate fitted with a joint shim, and in the same way gets over the disadvantage of rolled « repair » plates. Figure 13 clearly shows the groove formed by the die and the resultant camber in the top surface of the plate, Figure 14 depicts a joint fitted with these plates.

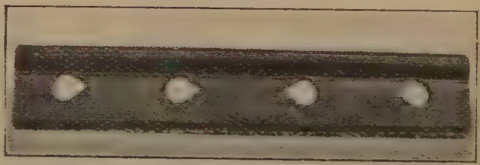

Fig. 13. — Reconditoned B. S. fishplate.

This process is widely used in Germany and is being increasingly adopted in this country. So far as cost is con-

cerned it is a mere fraction of the price of new fishplates. The system is patented by the Brinker Eisenwerk, Hannover,

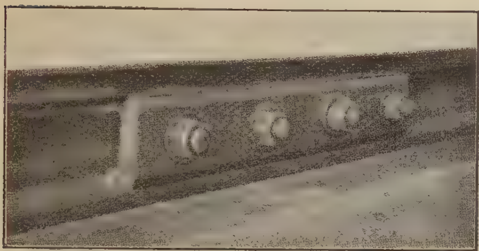

Fig. 14. — Joint with reconditioned plate.

and reconditioning is done by both British and German railways under licence.

Maintenance of joints.

The subject of rail joints cannot be dismissed without a reference to the importance of their proper maintenance. One of the purposes of rail joints has always been regarded in the past as the provision for the expansion and contraction of the rails under variations of temperature. Latterly this has been seen to be less important proportionately as the strength of the track and the ballast holding it has increased. The historic experiment of the Lehigh Valley Railroad in laying five miles of track with the rail-ends butted close together, thus allowing nothing for expansion, will be remembered. It was found that with the heavy rails, numerous sleepers, and ample depth and boxing of suitable ballast, no trouble whatever was experienced, although the line carried heavy traffic and was subjected to an intensely cold winter followed by a hot summer. The compressive stress induced by rise of temperature in rails which are prevented from expanding is evidently considerably less than the frictional resistance to distortion between the track and the ballast. Experiments with the use of very long rails have also indicated that the expansion to the theoretical amount corresponding with temperature variations does not by any means always take place.

In the past, although expansion gaps have been left between rails when they were laid in the track, the maintenance of the joints has often been such that the actual expansion could not take place. Hence, particularly on light traffic lines where ballasting has not been of a very elaborate description, buckling has occasionally taken place when there has been a sudden rise of temperature. It should, of course, have been possible to avoid such contingencies by proper attention to the fishplates. Nowadays in this country it is the almost universal practice to lubricate fishplates, but up till a few years ago there was a good deal of difference of opinion as to whether this was either desirable or necessary. On certain lines, for example, it was considered preferable not to lubricate fishplates but to work the bolts and leave two of them slightly loose in the spring of the year before hot weather was expected.

Now, as we have said, the practice of lubrication has become almost universal, but again the question of the best lubricant and the best method and frequency of its application does not seem to have been finally settled. In the spring of the year one of the duties of the platelayers is to go round the rail joints, loosen or remove the fishplates, clean them and apply to their upper and lower surfaces a lubricant. A mixture of rape oil and wagon grease has been found to be satisfactory for this purpose. In other cases coal tar and tallow mixed have been found effective. Experiments undertaken some time ago point to the probability that the most efficient lubricant is undiluted graphite grease applied with a stick. The lubricating power of this material is in the graphite, and it has

been found that one application of a sound graphite grease, such as Foliac, would remain good on well-maintained track for at least two years, thus saving the necessity of repeating the operation or lubrication every year. It is not always easy to get the platelayers to understand that this grease should be applied without dilution with oil, which in time evaporates, and in any case leaves the contact surfaces dry. The mixing of graphite grease with oil to such an extent as to enable it to be applied with a brush has the effect of reducing the amount of graphite on the contact surfaces.

Apart from the proper attention to fishplates and fishbolts, the packing of joint sleepers so that they remain firmly bedded on the ballast, both unloaded an under the load of passing trains, is of paramount importance. This can be done by forcing the ballast underneath the sleepers as far as it is possible to do so by means of blunt beaters, or alternatively by lifting the track high enough to allow of the insertion of a small flat shovel underneath from which chippings can be sprinkled to fill up the void. Where joint sleepers are brought close together, or approximately so, as they generally are when short fishplates are used, this latter method of fettling — known as shovel packing — would appear to be essential. The practice is, in fact, extending, not only in this country, but abroad, and is generally conceded to give better results with less expenditure of energy and more cheaply than the older method. It should be pointed out, however, that this is strictly only a method of maintenance, and that where a considerable lift is given with track on new ballast it is preferable to consolidate it by means of power-driven tampers.

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Gravity shunting yard

at Osterfeld-South, Germany.

(*The Railway Engineer.*)

The gravity shunting yard at Osterfeld South is an example of modern German practice in this class of work, and is equipped with apparatus manufactured by the Vereinigte Eisenbahn-Signalwerke, G. m. b. H., Berlin-Siemensstadt. The application of automatic devices to shunting yard service in recent years has awakened great interest in railway circles everywhere and is to be seen not only abroad, but also at Whitemoor, on the L. N. E. R. The cost of shunting operations in hump yards has been reduced by approximately 25 per cent in Germany by the use of scientific methods, and although each individual yard has distinctive features peculiar to itself, necessitating each case being carefully considered on its merits, Osterfeld-South Yard is broadly typical of many installations and has therefore been selected for this brief description.

General layout.

The layout of the yard is shown in figure 1, from which it will be seen that there are 43 classification lines having 48 pairs of points communicating with them, of which 8 are controlled and operated automatically by means of magazine apparatus, the remainder being governed by individual levers. The former are distinguished by hatched lines on the diagram. Points Nos. 106 *c/d* and 107 *c/d* have separate point machines but are controlled from the same magazine. The machines are of the A. C. type and are run on voltages varying from 180 to 220, according to the load, which is heavier in some cases than in others owing to point fittings, rodding, etc., varying. The whole of the control apparatus is contained in the cabin R2. The relays, magazines and insulated rails operate on D. C. at 12 volts, the detection circuits at 12 volts A. C. and lever locks at 15 volts A. C. Accumulators supply the D.C. and an emergency supply is made available if the main one fails.

Lever of control frame.

The lever frame is the most interesting part of the equipment and is illustrated in figures 2 and 3. It is made in desk form with metal panelling, enabling any handle to be operated comfortably by the signalman when seated. Particular attention bas been paid to making all parts readily accessible. The top sloping face is fitted with painted brass bars to represent the tracks concerned. The individual levers are really handles at the points of intersection and are provided with red lamps, white lamps being placed alongside the adjacent pieces. The red lamp glows when a vehicle is on the points, and when this is the case the lever is locked. A lever relating to a pair of automatic points has three positions, viz.: Normal (+), reversed (—) and middle. The other levers have no midway position, and the two types are further distinguished by bearing black and red numbers respectively. When in the middle position

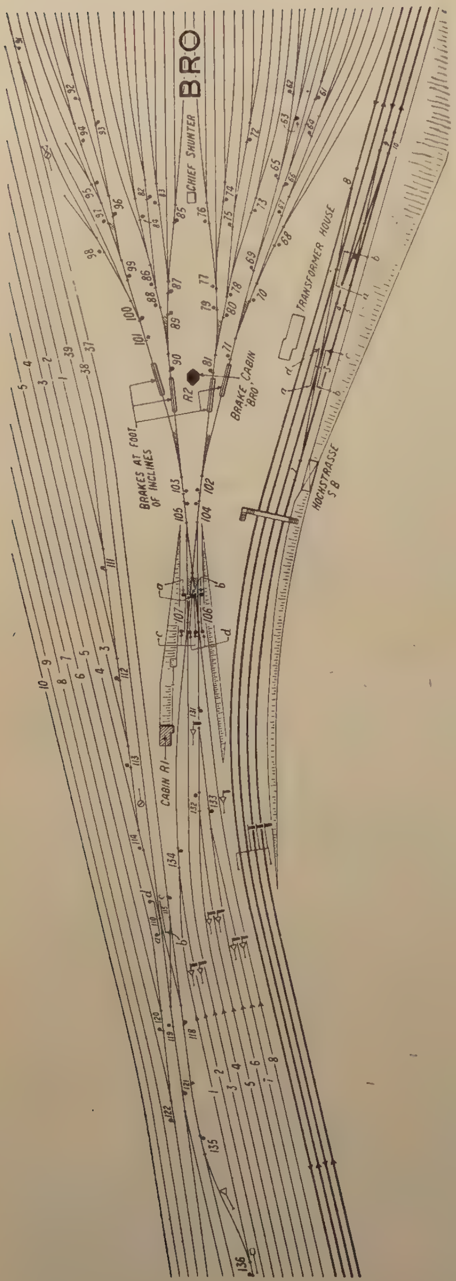

Fig. 1. — Hump bottleneck at Osterfeld-South Marshalling Yard.

the automatic point levers can be pressed down like hand plungers, and when so operated they cause the relative magazine to move forward one step and the control stored in them at that particular position to be cancelled. Another knob, or button, marked « L. T. », when depressed, acts similarly on all the magazines. Cut-out switches for the lamps and track circuit sections are provided to economise current at quiet periods.

Points Nos. 106 *c/d*, 107 *c/d*, 106 *a/b* and 107 *a/b* can be operated from either cabin R1 or R2, a switch being provided to enable this control to be selected as occasion requires.

Working of the system.

The principle of this system of working is to have the various routes required for the sorting of the vehicles in any particular train stored up in the magazine apparatus before operations begin, so as to avoid delays and confusion. The points are altered in position, when required, for a following vehicle by the previous one as it passes down from the hump and works the track circuits at the points. The magazine mechanism, which resembles similar mechanism used before for other purposes in train signalling, is thus the main element in the arrangement.

The working is briefly as follows :— The yard is divided into eight groups, there being a button on the desk for each one and one additional main button. To send a wagon to a particular line the signalman has only to press the appropriate group button and then the main button. Two pilot lamps are provided on the desk, the left normally burning. This goes out and the right-hand one lights up during the storing operation; when it is completed the normal condition is restored. If necessary a change can be made in the controls after a route has been completed in the

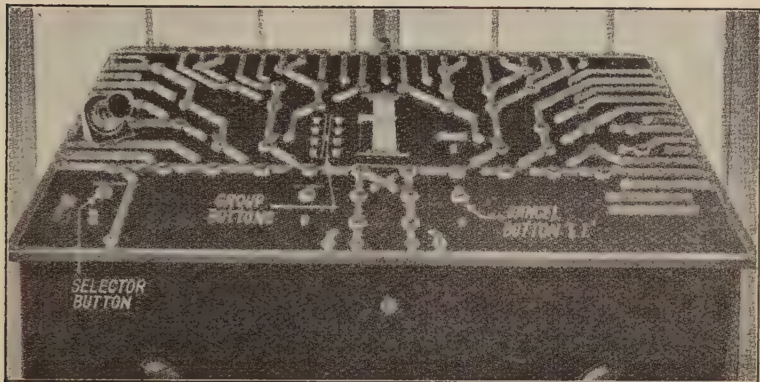

Fig. 2. — Top view of frame.

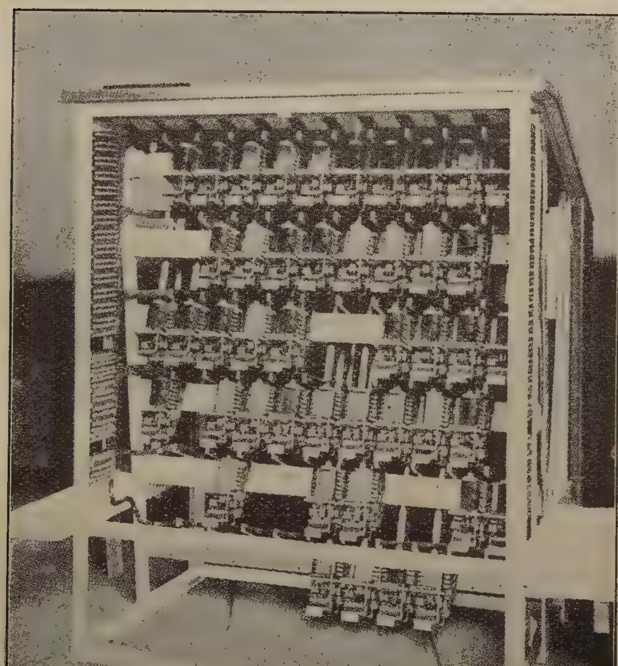

Fig. 3. — Back view of frame with the relays
and wiring.

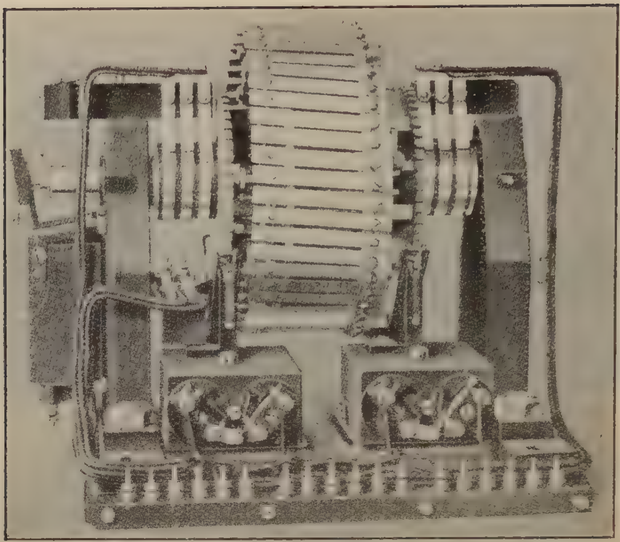

Fig. 4. — Magazine.

magazines by using the point levers for automatic points and replacing them in the middle position, when the automatic controls continue to function. Pilot lamps are provided to indicate when a particular magazine is empty, whilst to ensure absolutely reliable operation the insulated rails at the automatic points are connected on a special circuit to two track relays.

MISCELLANEOUS INFORMATION.

[621. 133 2 (.73)]

Semi-water-tube firebox developed by the Baltimore and Ohio Railroad.

(Railway Mechanical Engineer.)

The Baltimore & Ohio has developed and applied to a number of its heavy 2-8-2, 4-6-2 and 4-8-2 type locomotives a semi-water-tube firebox which can be installed inside the conventional firebox of stayed construction, with or without a combustion chamber. This development was in connection with a program of modernisation which the Baltimore & Ohio has had in effect for the past five years.

To modernize a locomotive built 10 or 12 years ago and increase the tractive force at high speeds it is necessary materially to increase the boiler horsepower. This is one reason why the Baltimore & Ohio developed the Emerson water-tube firebox which eliminates crown-sheet, radial and side water-leg staybolts, the only staybolts being in the throat sheet and backhead. This water-tube firebox has been applied to a number of locomotives on which complete new back ends have been required as well as to two of the Baltimore & Ohio test locomotives recently built by the Baldwin Locomotive Works (*).

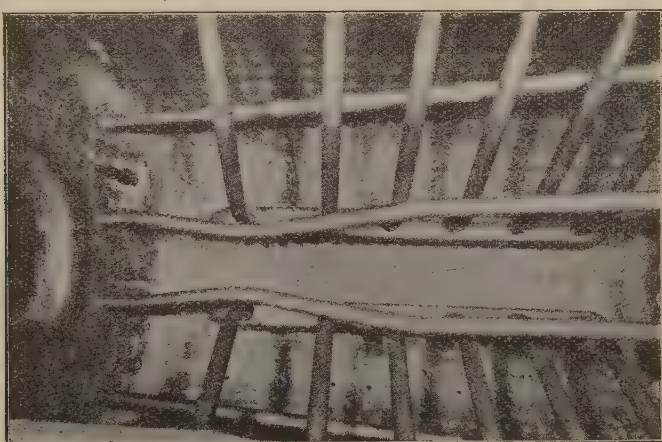

Fig. 1. — View inside the semi-water-tube firebox looking up toward the crown sheet.

The semi-water-tube firebox was developed to obtain a material addition to the heating surface from existing fireboxes. This firebox, shown in the drawing, consists of two troughs about 16 inches deep which extend longitudinally in the firebox and are welded to the crown sheet. The bottom of each trough is connected to the side water legs of the firebox by a number of circulating tubes. These tubes are rolled and beaded in both the side sheets and the troughs.

(*) A description of the Emerson water-tube firebox, which is referred to here, appeared in the August, 1931, issue of the *Railway Mechanical En,ineer*, page 397.

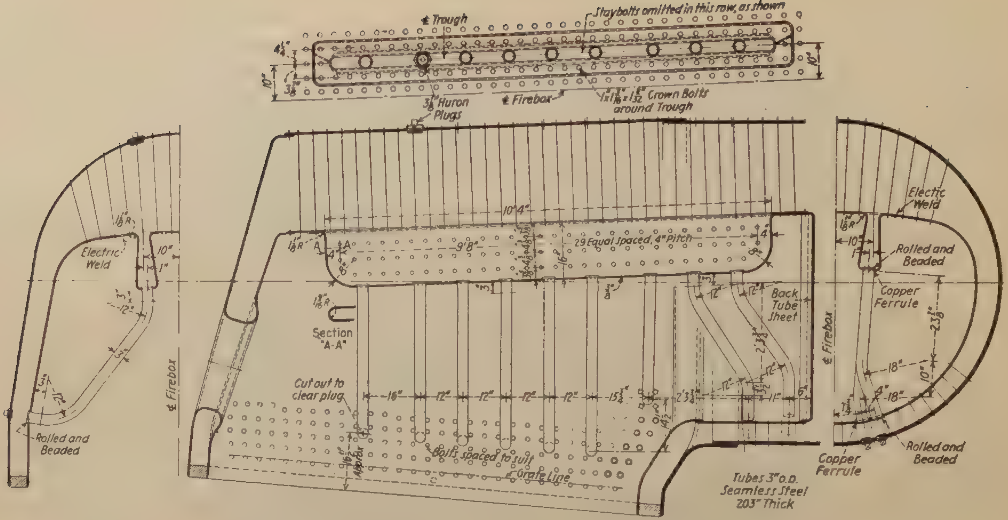

Fig. 2. — Semi-water-tube firebox developed by the Baltimore & Ohio and installed on a number of its locomotives.

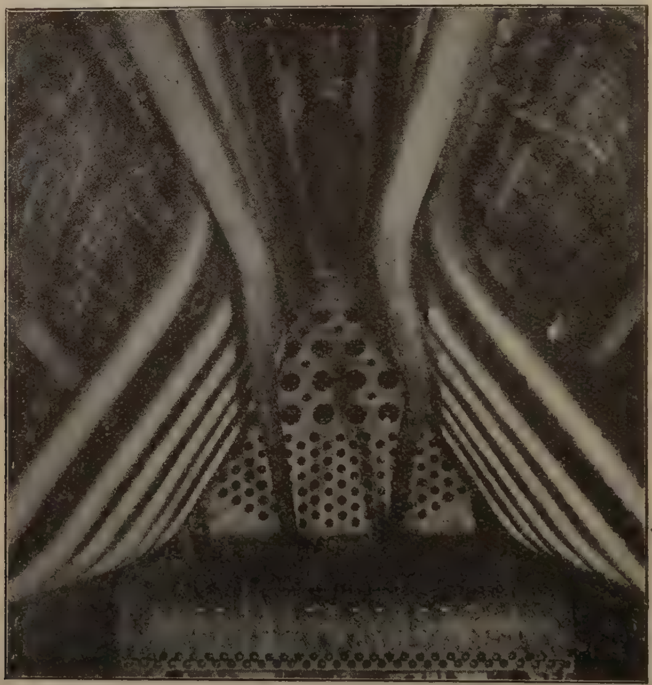

Fig. 3. — Firebox with semi-water-tube installation showing the back flue sheet and combustion chamber.

Increase in heating surface.

This semi-water-tube firebox effects a marked increase in direct firebox heating surface. The heating surface on the 2-8-2 type locomotive on which the first installation was made was originally 256 sq. feet. With the semi-water-tube firebox, an additionnal 74 sq. feet of heating surface was acquired, making a total of 330 sq. feet. The former firebox, by Cole's ratios, evaporated 14 056 lb. of water per hour, while the semi-water-tube firebox is capable of evaporating 18 173 lb. of water per hour, or an increase of 29 %.

Before conversion the firebox shown in the drawing had a heating surface of 327 sq. feet, including the combustion chamber. After the semi-water-tube firebox was applied, the heating surface was increased to 432 sq. feet. The evaporation with the original firebox, calculated according to Cole's ratios, was 18 004 lb. of water per hour and, after the semi-water-tube firebox was applied 23 793 lb. of water per hour, or an increase of 32 %.

Increased circulation.

Besides increasing the direct firebox heating surface, the semi-water-tube firebox increases the circulation in the side water legs of the boiler and is expected to prolong the life of the side sheets and staybolts. The rapid circulation set up by the semi-water-tube firebox will also act as a safety measure for the crown sheet. A rapid upward circulation is set up, causing an overflow of water onto the crown sheet, which will prevent the crown sheet from being pulled away from the staybolts.

The troughs are so designed that they are free to expand and move in all directions with the movement of the firebox. Opposite the ends of each circulating tube, in both the roof and side wrapper sheets, is a clean-out plug which is removed at washout periods, so that the water tubes can be thoroughly cleaned when the boiler is being washed out.

Brick arches are applied in the firebox. The arch tubes are installed in the usual manner and the arch brick is chipped out to clear the circulating tubes.

The locomotives to which these fireboxes have been applied are showing a marked increase in steaming capacity and the fireboxes have developed no trouble up to the present time. This design of semi-water-tube firebox is covered by patents in the U. S. A. and Canadian patents are pending.

[**621** .335 & **621** .43]

The possibilities of gas-electric locomotives,

by E. B. WALKER,

General Superintendent of Electric Lines, Canadian National Railways, Toronto, Ont.

(Railway Age.)

A number of gas-electric locomotives are now in daily operation in various classes of railway service, showing, in most cases, distinct advantages over the older type locomotives. Because the gas-electric locomotive can be easily designed to pull a 1 000-ton train at 10 miles an hour does not in any way mean that it would be equally satisfactory to design a locomotive to pull the same size train at 25 miles an hour and it is, therefore, of the utmost importance to ascertain, first, if the service required is definitely within the economic limits.

In considering the useful application of a gas-electric locomotive, it will be of advantage to study in a general way its own limitations and the limitations of the steam locomotive which it is proposed to replace. To assist in this consideration, two graphs are shown. The characteristic speed, tractive force and horsepower curves of similar sizes of steam and gas-electric locomotives are compared in figure 1 which is based on the curves of actual locomotives. The fuel costs at different percentages of loading, shown in figure 2, are based on limited data and are only representative. They serve, however, to illustrate quite satisfactorily the difference

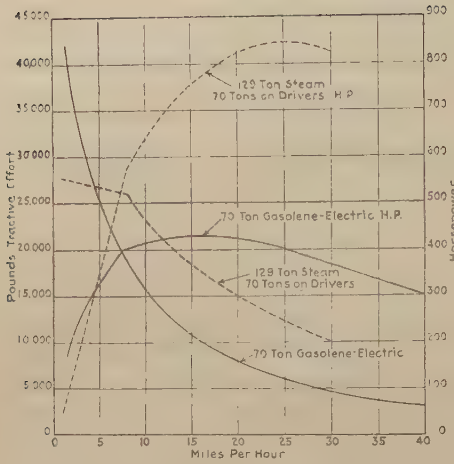

Fig. 1. — Comparative curves showing speed, tractive force and net horsepower at the rail, of steam and gas-electric locomotives.

in efficiency between steam and gas-electric locomotives under varying load conditions. Figure 1 indicates that the gas-electric locomotive has the advantage for slow speed and high starting tractive force. For higher speeds with heavy loads, it does not compare favorably with the steam locomotives. Figure 2 bears out the same conclusions. We can, therefore

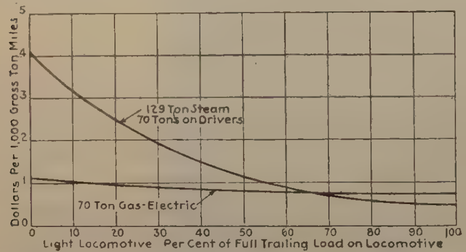

Fig. 2. — Comparative curves showing fuel cost per 1 000 gross ton-miles, steam and gas-electric locomotives.

assume that where continued sustained effort with short stand-by time is required, the steam engine has the advantage, and that for intermittent service with periods of light and heavy loads, such as switching, the gas-electric has interesting economies to offer.

These conclusions are borne out by actual results on a short line about five miles long where a mixed freight and light passenger service is maintained. The freight service consists of switching and short haul, and for this the gas-electric locomotive is well adapted. As the passenger service consists of moving one coach only, the gas-electric is also satisfactory, as it has plenty of speed capacity at low tractive force. Had the passenger service consisted of five or six coaches instead of one, the locomotive would have been entirely inadequate, although it is capable of handling 16 freight cars at slow speed. It is, therefore, necessary to make a complete investigation of the proposed service before deciding to change from the older type of power.

On the line in question, a 35-ton Whitcomb locomotive has operated without trouble or interruption for about sixteen months and during that time has reduced the fuel cost by 65 to 75 % and at the same time performed every service that the steam engine performed with the additional advantage of elimination of smoke, a feature much appreciated by the residents of the town.

Standard tested units used in construction.

One of the points stressed in deciding upon, in designing this locomotive was that every unit in its construction should be of standard and proved design, and that there should be no experimental features. The incorporation of experimental features in operating units is often a source of trouble. What the operator requires is a unit which will perform its service with a maximum of reliability and minimum of specialized attention. By selecting for this locomotive gasoline engines that were already in regular production, generators which were so standardized that they could be bought from stock, motors and trucks which had already given 20 years' good service, the requirements of the design were fulfilled, resulting in the satisfactory operation referred to above. In this connection, it must be remembered that the units employed are so simple in construction and operation that no electrician nor mechanic is required on the operating staff.

The net operating costs of such a locomotive depend largely on conditions governing the rail-

way. If rules permit, there is no necessity for having more than one man on the locomotive, as the gas-electric design lends itself easily to the center-cab type with full visibility in every direction. If reasonable care is taken of the equipment, maintenance cost should be very low. The ordinary electric equipment is good for 20 years at least, and, in the locomotive under consideration, the motors have already seen 20 years of service and are apparently good for another 20. Motors in this class of service should be operated at a lower cost than in the ordinary electric locomotive. If the equipment is conservatively designed, the motors should be large enough so that they can absorb all the power developed by the gasoline engines without overheating, and the low average operating voltage, together with the small amount of power behind the generator, tends to increase the life of the machinery, as compared with an electric locomotive where large amounts of power can be drawn from the overhead wire, or third rail.

The life of the gasoline engine in this service has yet to be determined, but here again it is safe to forecast low costs. In the locomotive under discussion, the cost of the gasoline engines is about 10 % of the cost of the entire locomotive. For 5 %, therefore, a spare engine can be carried in stock and, as a defective engine can easily be lifted out and replaced with a new engine, it is possible to keep a spare engine in good operating order by carrying out major repairs in a more efficient manner on the bench instead of in the chassis.

As a matter of interest and comparison, two new engines could be purchased per annum for less than the cost of the annual repair bills for the steam locomotive which was replaced. It is difficult to estimate how often a complete engine overhaul would be required. The locomotive in question has operated 16 months and outside of spark plugs, cleaning carbon, etc., the only repairs have been two distributor gears, one magneto distributor cap and one valve. None of these defects caused interruption to the service. In the case of the distributor gears, the magnetos supplied ignition and when the magneto failed the distributor supplied ignition. In the case of the valve, the cylinder in question was missing, but did not interrupt service.

At a convenient moment, the local garage replaced the valve and cleaned the carbon, etc., for a labor charge of less than $5. This is interesting as it indicates how easily this class of equipment can be operated without special maintainers.

Operator's influence on fuel consumption.

The fuel consumption depends partly on the intelligence of the operators, and it was found that when they became used to shutting down the engine immediately for every stop of more than a few minutes' duration, there was a substantial saving in fuel and the ease of starting and stopping is such that there is no difficulty in making use of this feature .

Another feature lending to economy is the ability of the locomotive to handle all light loads on one engine. In actual results, this locomotive will handle 125 gross ton-miles per U. S. gallon of gasoline when the engine or engines are fully loaded. This, however, runs as low as 85 ton-miles per U. S. gallon for high speeds and light loads. The oil cost at present is about 8 % of the cost of gasoline. The rate of consumption, undoubtedly, will increase as the engines become more worn, but at present it averages about 85 miles pr U. S. gallon.

One feature which may cause the operator to hesitate before purchasing a gas-electric unit is uncertainty as to its length of life. It would be hard to imagine, however, any type of railway power which is less subject to obsolescence. When it is remembered that the electric traction motor of today is not inherently better than that of 20 years ago, that trucks, wheels, locomotive frames and cabs are much the same, that electric generators and control equipment are not subject to any very rapid changes in design, it can be seen that 90 % of the locomotive should be good for many years. The engines will undoubtedly wear out, and marked improvements are being made from time to time in the design of internal-combustion engines. There is no doubt also that in the not too-distant future, the Diesel engine will be in commercial production at much lower prices and will eventually give as reliable and satisfactory service as the present gasoline engine.

This, however, need not trouble the purchaser of a gas-electric locomotive. When it is remembered that engines represent about 10 % of the cost, it will be appreciated how inexpensive it will be to replace them as they wear out, with engines representing a later development.

The purchaser of a well-designed gas-electric locomotive need have no apprehension that it may be superseded in a short time by something so much better as to render it uneconomical to use. There is no type of locomotive which lends itself more easily to unit replacement. Any of the units, engines, generators, or motors, can be replaced without upsetting the function of the remaining units, and thus a machine once purchased may be maintained in good operating condition for many years without undue expense.

CORRIGENDUM.

Bulletin, January 1933, Question IX, Cairo Congress :

Automatic train control and train stop. Special report by Herr W. Stäckel, Page 122, 8th to 10th lines.

Instead of :

« 12. The American intermittent inductive auto-manual system of the General Electric Company. »

Read :

« 12. The American intermittent inductive auto-manual system of the **General Railway Signal Company.** »

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